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ALEXANDER FREINDLING & LAURI HEITTO (eds.)

PRIMARY PRODUCTION OF INLAND WATERS

THE SECOND SOVIET-KARELIAN - FINNISH SYMPOSIUM ON WATER PROBLEMS
HELD IN PETROZAVODSK, USSR, 21 - 25 MAY 1990

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Abstract
In May 1990 the Second Karelian - Finnish Symposium on water problems was held in Petrozavodsk, USSR. The title of the symposium was 'Primary production of inland waters'. Results and methodological aspects of bacterioplankton, phytoplankton and macrophyte studies were presented in a total of 14 papers.

Keywords
primary production, bacterioplankton, phytoplankton, aquatic vegetation, lakes, rivers, Soviet-Karelia, symposium

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F O R E W O R D

In 1989 the first Soviet-Karelian - Finnish symposium on water problems was held in Petrozavodsk as a beginning of the cooperation between the Karelian Research Centre of the Academy of Science, USSR, and the National Board of Waters and the Environment, Finland.

The second symposium was held in Petrozavodsk in May 1990 according to the cooperation protocol for 1990. The title of the symposium was 'Primary production of inland waters'. The symposium included a two day seminar during which results and methodological aspects of bacterioplankton, phytoplankton, and macrophyte studies in lakes and rivers were presented in 14 papers. In addition, microscopical teamwork and scientific excursions were organized.

Lakes in Finland and Karelia have common features because of similar bedrock, soil and climate characteristics. Scientific cooperation in the field of inland water research and nature protection is therefore of great value. The cooperation between the two institutes is expanding.

The editors wish to thank all the authors who have made the papers presented at the symposium available for publication. We also wish to thank Mr. Lauri Haverinen for the numerous practical arrangements in connection with the symposium, Mr. Pertti Heinonen for the time spent revising the papers, Ms. Pirjo Lehtovaara for editing the manuscripts, Ms. Terttu Halme for the technical assistance of the drawings, Ms. Marianne Saari revising the English and Ms. Taina Saarinen for finishing the Russian part of the references in the articles.

Alexandr Freindling Lauri Heitto

CONTENTS

THE ROLE OF BACTERIOPLANKTON IN THE FORMATION OF ORGANIC MATTER IN LAKE ONEGA

Timakova T.M.
Karelian Research Center of Academy of Russia
Water Problem Department
185003 Petrozavodsk
Urickogo 50
Russia

1 I N T R O D U C T I O N

The primary production of lakes consists mainly of phytoplankton production. The role of bacterioplankton may be also very important (e.g. Kuznetsov et al. 1985, Romanenko 1985). The primary production of the autotrophic bacteria can reach 10-50 % of that of phytoplankton (e.g. Rudd 1980, Cloern et al. 1983). Biomass synthesis by heterotrophic bacteria is also a significant process.

According to Romanenko (1985), CO_2 fixation by bacteria takes place in the majority of ecosystems, especially in the water mass by both chemotrophic and heterotrophic micro-organisms with the predominance of the latter. Nearly 6 % of the bacterial biomass is formed from the CO_2 carbon by heterotrophic bacteria.

The present work aims at the estimation of the biomass production of phytoplankton and bacterioplankton in Lake Onega under a natural matter cycle (Onega Proper) and under a considerable intake of allochthonic organic matter (Petrozavodsk Bay and Kondopoga Bay).

2 M A T E R I A L A N D M E T H O D S

The study was carried out in 1989 from June to October. Phytoplankton biomass production was determined by the method described by Timakova and Vislyanskaya in this volume. Bacterial production was evaluated from the dark CO_2 assimilation by the radiocarbon method described by Romanenko and Kuznetsov (1974). In this case the latter was assumed to be 6 % of the bacterial biomass growth (Romanenko 1965).

The studied bays are influenced by a natural river, slope flow, and antropogenic factors. They are clear-watered and deep with a high annual O_2 saturation of the water. The mean concentrations of SO_4^{-2}, NH_4^- and NO_3^- ions are low, although particularly in Kondopoga Bay, these vary considerably in different parts. At the same time, the bays differ greatly in the character and content of organic matter (OM).

3 RESULTS

In Petrozavodsk Bay the concentration of OM varied from 13.7 to 15.7 mg l^{-1}. More than 50 % of it was allochthonic. In Kondopoga Bay OM content was mainly determined by the anthropogenic flow amounting from 13 to more than 60 mg l^{-1}. In Onega Proper the amount of OM was 9-16 mg l^{-1} predominated by autochthonic OM (Pirozhkova 1990).

The lowest values of the dark CO_2 assimilation were measured in Onega Proper (0.01-0.21 µg l^{-1} d^{-1} C, mean 0.09 µg l^{-1} d^{-1} C), indicating a weak synthesis of bacterial biomass. In the bays the fixation of CO_2 carbon by the bacteria increased in proportion to the increase of the OM content in the water. The CO_2 fixation in Petrozavodsk Bay was 0.1-0.91 µg l^{-1} d^{-1} C (mean 0.36 µg l^{-1} d^{-1} C), in the central part of Kondopoga Bay 0.23-2.40 µg l^{-1} d^{-1} C (0.85 µg l^{-1} d^{-1} C) and in the upper part 1.40-5.10 µg l^{-1} d^{-1} C when the water was at its warmest (Fig. 1). In the upper part of Kondopoga Bay the high CO_2 absorption was possible due to an increase in the proportion of chemosynthesizing bacteria in the bacterial community. According to the results of heterotrophic CO_2 assimilation, Onega Proper is oligotrophic and the bays are mesotrophic.

The distribution of the bacterial CO_2 fixation in the water mass depended on the temperature. After the establishment of summer stratification the maximum values were confined to the surface layers. This layer increased along with the temperature of the water up to 10 m in Onega Proper and up to 15-20 m in the bays. In the deeper layers with low temperatures, CO_2 assimilation of bacteria was 1.5-9 times weaker during the whole year than in the surface layers (Fig. 1). This fact indicates that the bacterial biosynthesis in the main part of the water mass is not very high.

Seasonal fluctuations of heterotrophic CO_2 assimilation were stronger in the eutrophic basins than in Onega Proper (Fig. 1). The early warming of the water mass and favourable trophic conditions lead to a 4-9 times more intensive bacterial biosynthesis. The process was activated when the maximum development of planktonic algae was reached, peak values being observed in August-September. In Onega Proper this process coincided with the dynamics of the OM production by phytoplankton.

Heterotrophic CO_2 fixation in Onega Proper was 3.9-10.0 mg m^{-2} d^{-1} C, and in the bays 2.9-121.7 mg m^{-2} d^{-1} C (Fig. 2) being 7-15 % and 14-40 %, respectively, of the phytoplankton biomass production. Supposing that this contains only 6 % of total bacterial biomass production (Romanenko 1965), bacterial production was equal to primary production.

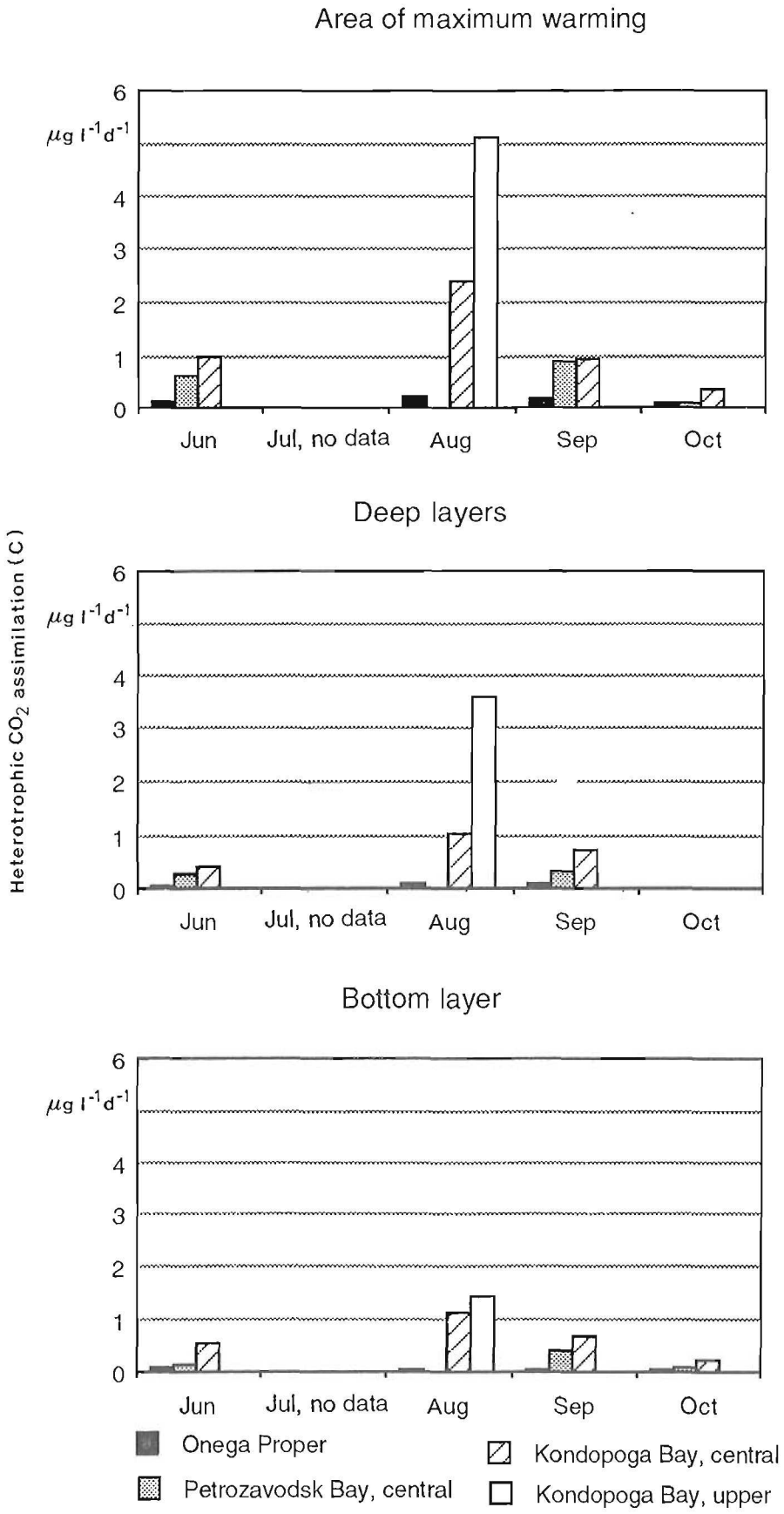

Fig. 1. Measured heterotrophic CO_2 assimilation (µg l^{-1} d^{-1} C) in the studied areas in different depths during the study period. Measurements in the upper part of Kondopoga Bay were made in August only.

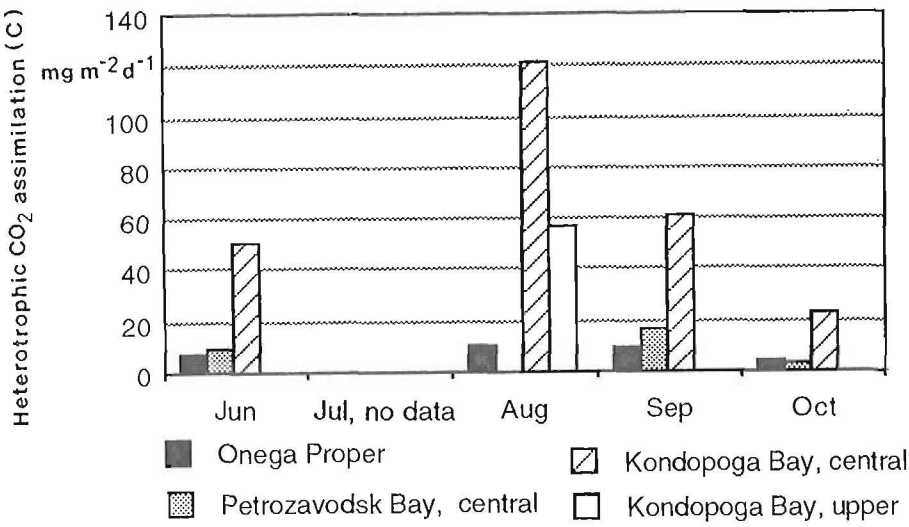

Fig. 2. Heterotrophic CO_2 assimilation per surface area (mg m^{-2} d^{-1} C) in the studied areas during the study period. Measurements in the upper part of Kondopoga Bay were made in August only.

The bacterial production values were 0.2-3.4 µg l^{-1} d^{-1} C in Onega Proper and 1.6- 81.6 µg l^{-1} d^{-1} C in the bays (Fig. 3). Production depended more on the total OM content in the water than on the phytoplankton biomass, which indicates the important role of the allochthonic OM in the bacterial biosynthesis.

Measured values of bacterial biomass production (µg l^{-1} d^{-1} C) were 1-2 times lower than those of phytoplankton biomass production, but bacterial production per area (mg m^{-2} d^{-1} C) (Fig. 4) was equal and in the bays sometimes even 2.5-9 times greater. This was the case especially in the autumn, when the phytoplankton production decreased sharply. During the season daily bacterial production per surface area exceeded phytoplankton production by 5 times in central parts and by 6 times in upper parts of Kondopoga Bay and by 1.5 times in Onega Proper (Fig. 5).

Such a relation is not typical, but it can be explained by the fact that bacterial production was measured in the whole water column down to the bottom, but phytoplankton production only in the trophogenic layer (max. 17 m). In addition, extracellular phytoplankton production was not taken into consideration in the account of phytoplankton production. Of the new synthesized organic matter, it can reach 30 % in oligotrophic (Bulion 1983) and up to 44 % in eutrophic waters (Watanabe 1980). It is important to note the enormous amount of allochthonic organic matter in the upper part of the bays.

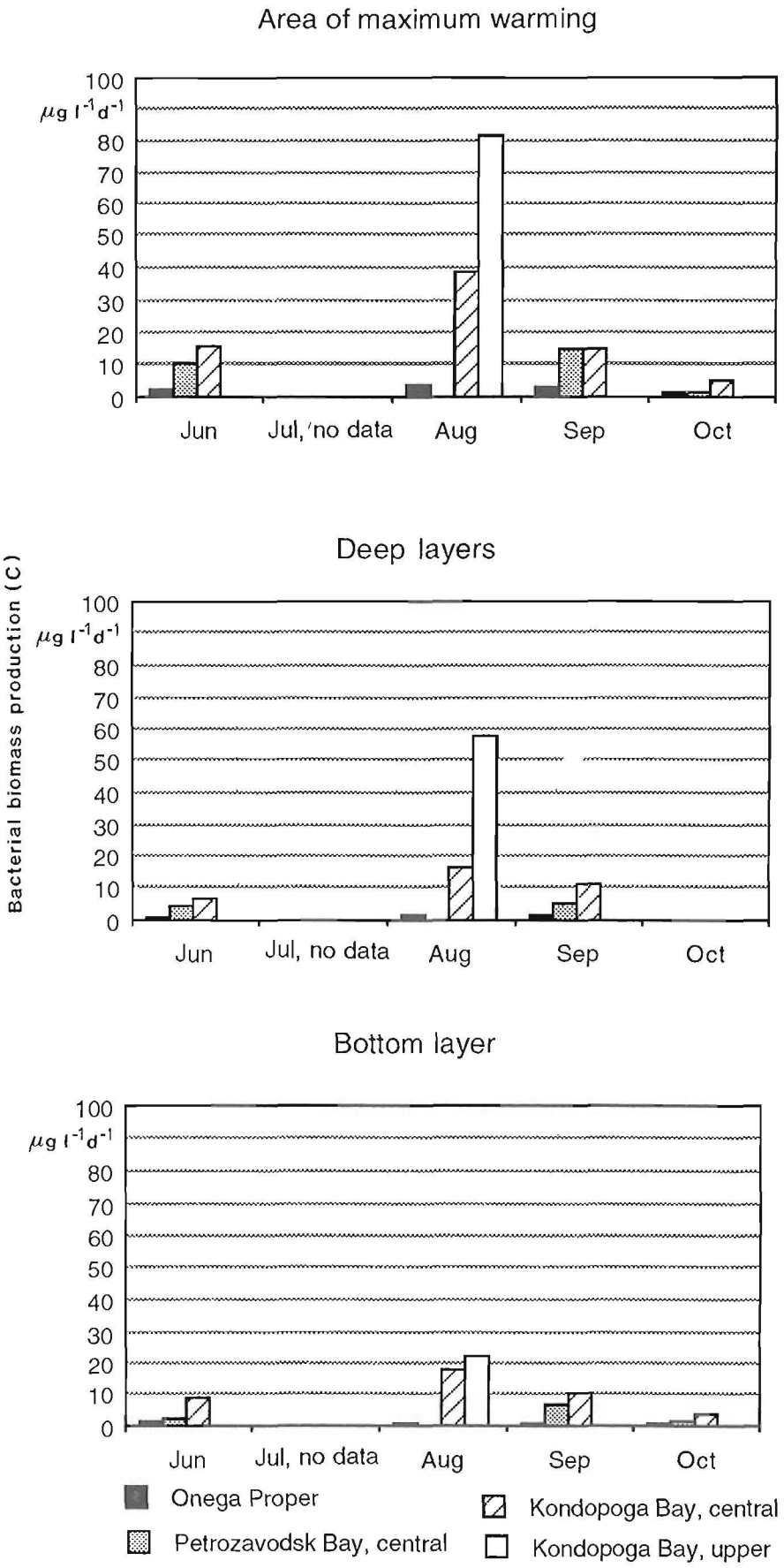

Fig. 3. Measured bacterial biomass production (μg l^{-1} d^{-1} C) in the studied areas in different depths during the study period. Measurements in the upper part of Kondopoga Bay were made in August only.

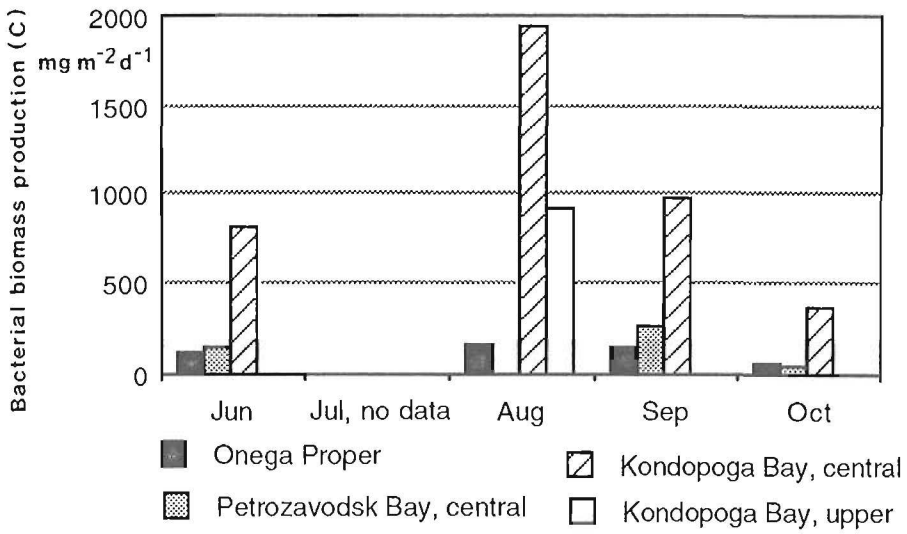

Fig. 4. Bacterial biomass production per surface area (mg m^{-2} d^{-1} C) in the studied areas during the study period. Measurements in the upper part of Kondopoga Bay were made in August only.

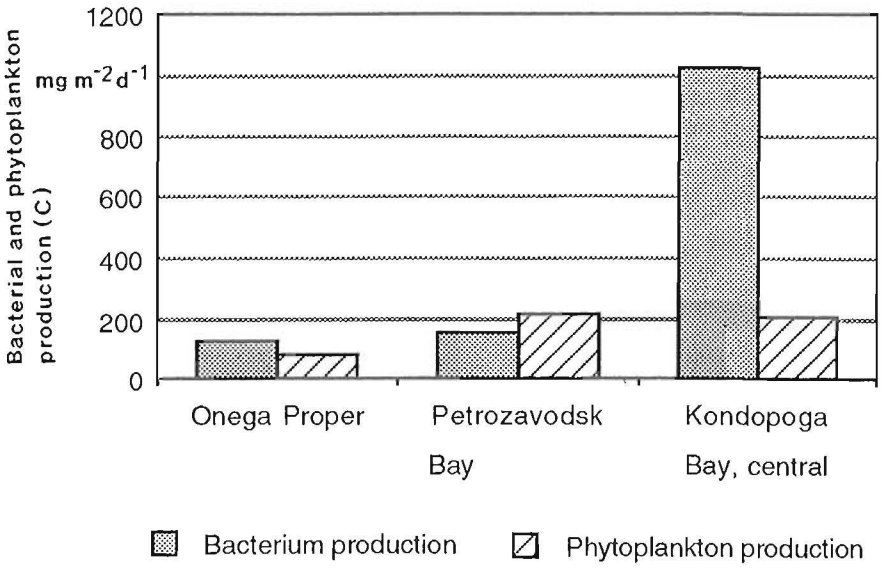

Fig. 5. The mean daily bacterial and phytoplankton production per surface area (mg m^{-2} d^{-1} C) in the studied areas during the study period.

4 CONCLUSION

The data, obtained for the three parts of Lake Onega indicates the important role of the bacterioplankton in the biosynthetic processes of CO_2 fixation. Low intensity of the bacterial biosynthetic processes was characteristic of Lake Onega, particularly in Onega Proper. However, in deep waters bacterial biomass production per surface area can be equal to or even greater than phytoplankton biomass production, because bacterial production can be measured down to the bottom. Phytoplankton production can be measured only in the trophogenic layer. This indicates the great importance of the bacterioplankton for the development of trophic relations even in a lake that is as slightly exposed to direct anthropogenic impact as Onega Proper.

The same phenomenon has been observed in Lake Ladoga (Kapustina 1990) and in a number of lakes of the Karelian Isthmus (Chebotarev 1984), as well as in the oligotrophic-mesotrophic reservoirs of Buhtarlinskoe and Minchegaurskoe (Gulaya 1975, Salmanov 1960), and it is apparently also characteristic of the deep basins of the so-called "transitional" type.

However, from the point of view of energy it is difficult to explain such a strong excess of bacterial production in Kondopoga Bay and Onega Proper merely by this short account of phytoplankton production and by the influence of the allochthonic component in the water of the bays during the year. One possible reason is the relatively imprecise method of determining bacterial production, which can lead to an overestimation of results.

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ENVIRONMENTAL FACTORS AFFECTING PHYTOPLANKTON PRODUCTION IN SMALL, HIGHLY HUMIC LAKES

L. Arvola
Lammi Biological Station, University of Helsinki,
SF-16900 Lammi, Finland

During the last 10 years several research programmes dealing with phytoplankton production and related environmental factors such as water temperature, light chemistry, bacterial activity and zooplankton grazing have been carried out in the Evo area, in southern Finland. The results indicate that the factors affecting the primary productivity of phytoplankton in small humic lakes may vary from lake to lake and from season to season within a lake.

The main factor limiting productivity in late autumn and beneath ice in winter is light intensity, whereas in summer the limiting factors are nutrients and zooplankton grazing. In spring, after ice has melted, there is usually a brief period when phytoplankton production can be very intense (in the surface up to 1 g $m^{-3} d^{-1}$ C). This is due to the high concentration of phosphate-phosphorus and inorganic nitrogen as well as the lack of zooplankton grazing. Later in summer zooplankton grazing is so strong in many studied lakes that some algal species (e.g. many green algae) are able to survive only in deeper water layers, where light intensity is low (< 10 µmol $m^{-2} s^{-1}$), oxygen concentration is reduced or water is anoxic, and therefore no or only few zooplankters are present and grazing on algae.

In many humic lakes the most abundant algal species are flagellates, and by swimming some of these are capable to migrate diurnally up and down through the thermocline and chemocline in water column. This migration by some alga species, particularly some cryptophytes, may contribute to their growth rate, because they are able to retrieve nutrients from deeper depths where nutrient concentrations are usually much higher than near the surface, and to their survival, because the timing of their up-and-down movements are reverse compared with most zooplankton species.

Altogether, our results strongly suggest that besides the morphometry of a lake basin and its catchment area, water colour is a main factor determining the primary productivity of phytoplankton in small lakes. This response is not only direct through light attenuation because of humic substances, but also indirect because of steep thermal and chemical stratification of the water column. In addition, the foodweb relationships between bacteria, algae and zooplankton seem to play an important role in the productivity of a lake.

In conclusion, although primary production of phytoplankton may vary to a large extent in different humic lakes because of the differences in the environmental conditions, the annual primary phytoplankton production is typically rather low (< 20 g $m^{-2} a^{-1}$ C) in most of these lakes.

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PHYTOPLANKTON IN SOME LAKES AND RIVERS OF KARELIA

Chekryzheva, T.A.
Karelian Research Center of Academy of Russia
Water Problem Department
185003 Petrozavodsk
Urickogo 50
Russia

1 I N T R O D U C T I O N

During 1972-1988 investigations of phytoplankton were carried out in the 44 Karelian water bodies including 27 lakes and 17 rivers belonging to the drainage basins of the White Sea and the Baltic Sea. The information on the phytoplankton of these water bodies is not sufficient and is limited to data of algological investigations of the lakes and rivers located in the area of the biological station of Borodinskaya (now Konchezerskaya) (Korshikov 1917, Chernov 1927a, b, Rusanova et al. 1977a, b, Chekryzheva 1978, Balonov 1979, Ieshko 1989). There is also some more information on the phytoplankton of the River Kem, lakes Middle Kuito and Roppomo (Trifonova 1973). Original material on the species composition of algae in all the other lakes studied has been published by the author for the first time in some reports of the Karelian Scientific Centre during 1982-1989 (Chekryzheva 1982a, b, 1984, 1985, 1989, 1990, Chekryzheva and Vlasova 1988), and it has also been presented at All-Union and regional conferences (Kharkevitch et al. 1983, Chekryzheva 1986, 1987, Gordeeva et al. 1986).

Most of the works are concentrated to the taxonomy and ecology of algae, to the study of the structure of phytoplankton communities and to the definition of the dominant species. In addition, these works give information on the seasonal succession of phytoplankton. The number of species and the total biomass are determined, and the spatial structure (horizontal and vertical) of the algocoenosis and the indeces of saprobity are evaluated. An ecological characteristic including the reaction of the species to salinity and acidity is given, and their habitat and geographical distribution are indicated.

2 M A T E R I A L A N D M E T H O D S

2.1 STUDY AREAS

A total of 20 lakes and 12 rivers have been studied in the drainage basin of the White Sea:

1) The lake-river system of the River Kem including the lakes Lower, Middle, and Upper Kuito, Koivas, Poppalijarvi, Okunevo, Kurojarvi, Jurikojarvi, Roppo-

mo, Panozero, Alanjarvi, Jushkozero, Julyjarvi, Haapajarvi, Kurojarvi, Nizhojarvi and the rivers Muezerka, Kem, Chirka-Kem.

2) The lake-river systems of the Karelian and Pomorian coasts of the White Sea including the lakes Sumozero, Pulozero, Shuezero, and the rivers Shuja (of the White Sea), Nyuhcha, Kolezhma, Suma, Kem.

3) The water area of the northern side of the White Sea- Baltic water way from the northern part of Vygozero up to the 19th lock including the flooded lakes of Voitskoe and Shavan and the Parandovskii rach, Palakorgskii, Matkozhnenskii, Vygostrovskii ponds and the mouths of the rivers Onda, Letnyaya and Lower Vyg.

4) Lake Paanajarvi with the rivers Sova, Sel'ka, Myantu, Oulanka-Joki and Olanga flowing into it.

A total of 7 lakes and 6 rivers have been studied in the drainage basin of the Baltic Sea:

Lakes Vendurskoe, Uros and Rindozero of the Vohtozero-Vendurskoe group and the lakes of the River Shuja drainage basin (the main inflow of Lake Onega) viz. Pertozero, Suojarvi, Iso-Pyuhajarvi and Syamozero with the rivers Kivach, Kudoma, Sudak, Small Suna and Imat brook flowing into it.

2.2 PHYTOPLANKTON

Phytoplankton samples of 0.5-1 litres were taken with a Ruttner sampler from the surface to the bottom at the interval of one meter. Samples were fixed with iodine-formalin (Kuzmin 1975), concentrated during 10-15 days of sedimentation, condensed with a fine-mesh gas or membranous filters (pore diameter 0.9-1.0 µm) soon after the sedimentation. Cells were counted in a Nazhotta chamber (0.02 cm^3) with a microscope. The biomass of algae was measured with a volume method, comparing the cell shape with a similar geometrical body (Fedorov 1979). Cell specific weight was taken as 1 g cm^{-3}. Special treatment of material was necessary for the determination of the diatom species. Various manuals were used for the identification of the algae species (Elenkin 1938, Identification manual of the fresh water algae of the USSR, 1951, 1953-1955, 1959, 1962, 1980, Korshikov 1953, Kosinskaya 1960).

For the quantitative estimation of water quality the Sládecek modification of the Pantle-Bukk method of saprobic indicators was used (Makrushin 1974). When calculating saprobity index for a water body the following formula was used:

$$S = \frac{\Sigma (n \cdot s)}{\Sigma n} \qquad (1)$$

where n = amount or biomass of indicated species
s = saprobity of a species
S = average index of saprobity

Saprobity indices were calculated according to the biomass of the species. Improved lists of indicator species were used with regard to the references of other authors (Anon. 1974, Anon. 1977). For the determination of the saprobity degree the following scale was accepted: saprobity index less than 1 characterises the water as xenosaprobic; from 1 to 1.5 as oligosaprobic; 1.5-2.5 - β mesosaprobic, 2.5-3.5- α-mesosaprobic; 3.61-4.5 - polysaprobic. On the basis of water quality the following groups can be distinguished: very pure, pure, fairly polluted, highly polluted and extremely highly polluted waters (Anon. 1983).

3 RESULTS AND DISCUSSION

3.1 SOME CHARACTERISTICS OF THE STUDY AREAS

Kuito lakes are the largest in the northern part of the Republic their water surface being 140 to 250 km^2, average depth no more than 10 meters and maximum depth 30 to 40 meters. These lakes are of the oligotrophic polyhumosis type. Kuito lakes were under natural conditions up to the middle of the 1950's. Then the water level in Middle and Lower Kuito rose as a result of their conversion into a single Jushkozero reservoir.

All the numerous lakes of the lake-river system of the River Kem are lakes with a short residence time. They are small in area (up to 10 km^2) and shallow (with a depth of 2-5 m). The water level of these lakes greatly depends on the River Kem and Chirka-Kem.

The catchment area of the River Kenti is 3.4 % of that of the River Kem. The length of the River Kenti is 75 km, and it passes through a number of lakes (Lake Okunevo, Lake Kurojarvi, Lake Poppolijarvi, Lake Jurikojarvi, Lake Koivas), the area of which varies from 0.3 (Lake Okunevo) to 20 km^2 (Lake Koivas). These lakes are mostly shallow. Their average depth is 2.5 to 4 m, the maximum 21 m in Lake Koivas. Lake Paanajarvi (water surface area 23.6 km^2) is a deep (maximum depth 128 m, average 37.8 m), coldwater lake of oligotrophic type with a short residence time.

Besides the main inflows to the Onega Bay of the White Sea, 25 small rivers flow into it, the average annual discharge being less than 2 km^3. They make up about 25 % of total inflow entering into this part of

the White Sea. The largest of them are the Suma River with the lakes Sumozero and Pulozero, the Shuja River with Lake Shuezero and the rivers Nyuhcha and Kolezhma. Lake Sumozero is the largest of these lakes. Its surface area is 73 km^2, average depth 7 m, and maximum depth 19 m. These lakes are mesohumic.

The main characteristics of the lakes of the Baltic Sea drainage basin are given in Table 1.

Table 1. Lake surface area, mean and maximum depth and trophic type of the lakes of the Baltic Sea drainage basin.

Lake	Lake surface area (km^2)	Mean depth (m)	Maximum depth (m)	Trophic type of the lake
Pertozero	12.8	11	37	oligotrophic
Syamozero	266	6.7	24.5	mesotrophic
Vendurskoe	10.1	6.2	13.4	oligomesohumic
Uros	4.26	2.8	9.5	oligotrophic
Rindozero	1.84	3.9	9.5	oligotrophic
Suojarvi	58.5	3.5	24	mesotrophic
Iso-Pyhajarvi	8.8	4.3	12	polymesohumic

The water of these rivers and lakes had low mineralization value, neutral reaction and it was poor in nutrients. The oxygen situation was satisfactory during the year. The organic matter of the lakes was mainly of natural origin. During the open water period the thermal stratification was characteristic of high-latitude shallow water bodies. The summer stratification was often unstable. All the basins studied were variously exposed to anthropogenic influence.

3.2 PHYTOPLANKTON

Phytoplankton species diversity was high in the water bodies studied: 451 species, varieties and forms were observed. In terms of number of taxa diatomic algae dominated the plankton composition followed by green (Chlorophyta), yellow-green (Chrysophyta), blue-green (Cyanophyta), pyrrophyteous (Pyrrophyta), euglenoids (Euglenophyta) and Xantophyta (Fig. 1). This tendency was characteristic of all the water bodies studied. Comparison of the phytoplankton species composition of different water body groups revealed a rather low degree of similarity. The occurrence of the same species was as a rule not higher than 30 %.

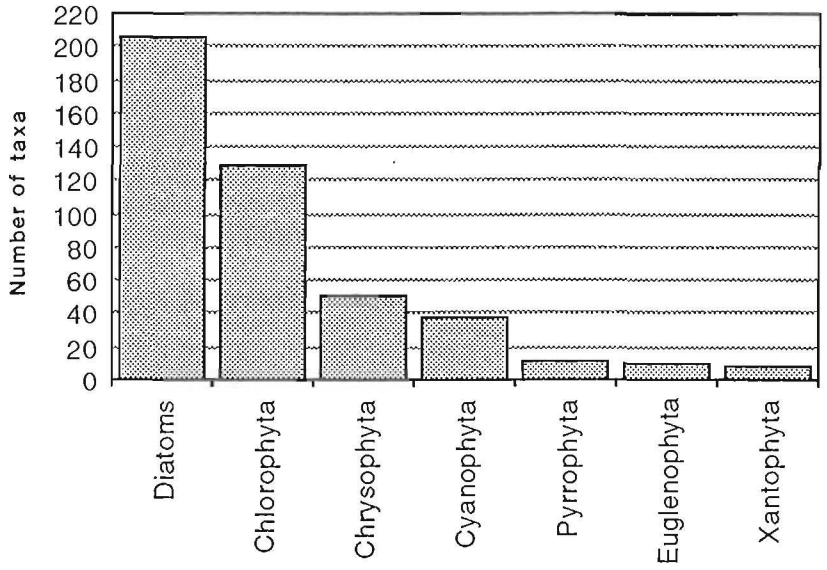

Fig. 1. Number of taxa of different taxonomical groups in the water bodies studied.

In the following genera of the diatomic Pennatophycea class the number of taxa was highest: *Eunotia* (27 taxa), *Navicula* (20 taxa), *Pinnularia* (17 taxa), *Surirella* and *Nitzschia* (12 taxa each), *Fragilaria* (10 taxa), *Cymbella* (9 taxa), *Synedra* (8 taxa) and *Gomphonema* (7 taxa). The centrophy class consists of the following genera: *Melosira* (11 taxa), *Cyclotella* (5 taxa), *Stephanodiscus* (4 taxa) and *Rhizosolenia* (2 taxa). The high number of taxa is determined by sufficient concentration of silicon, which was not a limiting factor during the whole growing season.

Yellow-green algae were represented by 51 taxa of the following genera: *Dinobryon* (16 taxa), *Mallomonas* (14 taxa) and small forms as well: e.g. *Stenokalyx*, *Kephyrion*, *Pseudokephyrion* and *Chrysococcus*. Their diversity is favoured by the active forms of iron in low pH values (Guseva 1952). Most of the yellow-green algae are found during cold seasons, causing the bloom of water in early spring and late autumn.

A high diversity of green algae belonging to chlorococcus, desmidious, and filamentous forms was characteristic of the Karelian water bodies studied. Euglenoids were variously represented by the species of the following genera: *Trachelomonas* (6 taxa), *Phacus* and *Euglena*. The following taxa were found of the *Xanthophyta*,: *Tribonema*, *Istmochloron*, *Centritractus*, *Goniochloris* and *Ophiocytium*. The pyrrophyteous were represented by cryptophytous (*Cryptomonas* and *Chroomonas*) and peridineous (*Peridinium* and *Ceratium*).

The blue-green algae were represented by 38 taxa and varieties mainly of the following genera: *Anabaena* (6

taxa), *Aphanizomenon*, *Merismopedia*, *Aphanothece*, *Gomphosphaeria*, *Gloeocapsa*, *Lyngbya*, *Rivularia*, *Oscillatoria* and *Woronichinia*. Short-term "blooms" in the development of blue-green algae in the Karelian basins are mainly observed during the second half of the summer.

Most of the taxa observed (230 or 54.1 %) are planktic forms. The proportion in planktic to benthic forms was highest in pyrrophytous (100 %) and lowest in diatoms (47 %) (Fig. 2). Of the diatomic planktic algae 26 % were litoral, 20 % pelagic, and 1 % epiplanktic.

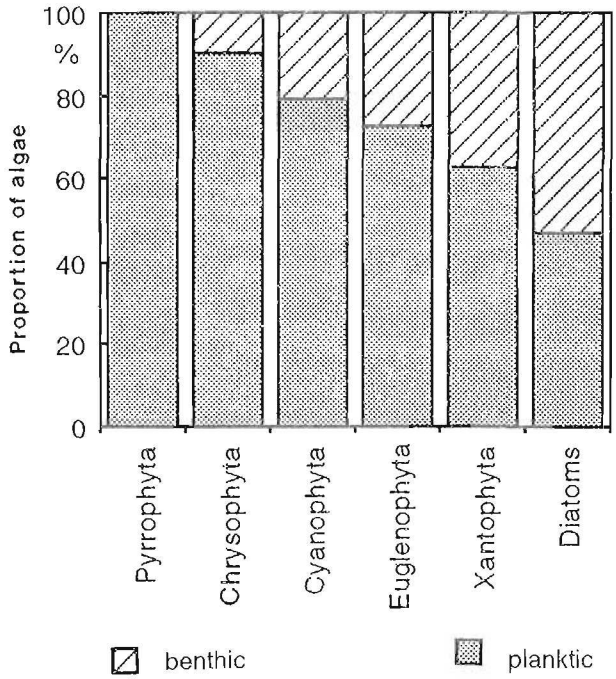

Fig. 2. Proportions of benthic and planktic algae in different taxonomical groups in the water bodies studied.

Halophobes were represented by 53 taxa and halophiles by 30 taxa. High density of *Tabellaria fenestrata*, *Asterionella formosa*, *Dinobryon bavaricum*, *D. sociale*, *Ureglenopsis americana*, *Anabaena scheremetievi*, *Microcystis pulverea*, *Gloeocapsa turgida* were characteristic of the weakly mineralized waters of the Karelian lakes (Kitaev 1984). Volkova et al. (1969) observed the same taxa in some small mesotrophic lakes in the forest zone in the North-West of the European part of the USSR (North of the Karelian Isthmus and the region of Valdai Upland). Mesohalobes species of *Nitzchia sigma* and two eurigomendus halophytes, *Cocconeis pediculus* and *Navicula cryptocephala*, preferring waters of high salinity, were observed.

In respect of pH the following groups were observed:

indifferents (58 %), alkaliphilous (21.8 %) and acidophilous (20.2 %) forms, the presence of which indicates the inflow of mire waters from the watershed area. *Woronichinia naegeliana, Coelosphaerium microporum, Peridinium cinctum, Ceratium hirundinella, Crucigenia rectangularis, Synura uvella, Dinobryon bavaricum, Mallomonas caudata* and *M. tonsurata* are found in humic waters (Kharkevitch 1960, Volkova et al. 1969). They were observed in humic water bodies in this study also.

According to geographical distribution, the group of cosmopolite forms (302 taxa or 78.4 %) with a significant proportion of boreal (i.e. algae of the temperate latitude) and northern-alpic forms were dominant in the phytoplankton of Karelian lakes and rivers. This fact outlines the psychrophilic character of algaflora in the Karelian lakes and rivers.

There was no estimation of the phytoplanktic saprobity for the most basins studied. Most of the taxa (87 %) of the 202 indicators of sabrobity belonged to oligo, oligo-β and β-mesosaprobic forms. Indicators of very pure water were very scanty, mainly diatoms such as *Achnanhtes lanceolata, Ceratoneis arcus, Cymbella helvetica, Eunotia lunaris* and *Meridion circulare*. Species characterizing β - α and α-saprobic conditions were observed and only *Chlorella vulgaris* belonged to P-α -saprobic forms. Saprobity index values, estimated with the Sládecek modification of the Pantle-Bukk formula, were at the range of 1 to 2.5. This indicates as a rule the oligo-β-mesosaprobic character the water bodies studied.

Planktic algae biomass fluctuated from 0.01 to 1.5 g m^{-3} in the summer. Diatomic algae usually predominated although some parts of the lakes were characterized by an intensive pyrrophytous development. A brief water "blooming" caused by populations of blue-green algae (e.g. *Oscillatoria agardhii, Aphanizomenon flos-aquae, Gloeotrichia echinulata*) was observed in some lakes during the second half of the summer. Total phytoplankton biomass during these periods exceeded 10 g m^{-3}.

The vertical distribution of algae was characterized either by a high concentration of phytoplankton biomass in the upper two meter layer and its even reduction with depth or by the additional formation of the second maximum in the metalimnion layer.

Species composition and biomass of phytoplankton were poor in winter. Both even and uneven vertical distribution of phytoplankton was observed. Sometimes a high concentration of algae biomass was noted in the underice layer.

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PHYTOPLANKTON AS INDICATOR OF EUTROPHY

Liisa Lepistö
National Board of Waters and the Environment
PB 250 SF-00101 Helsinki, Finland

1 I N T R O D U C T I O N

As dominant primary producers algae are in a key position compared to other groups of organism. The spreading potential of algae is known to be high and many species are cosmopolitans but their occurrence is influenced rather by the water quality than the geographical location (Round 1981). Even a small supply of nutrients may in an oligotrophic lake raise the trophic state to a higher level. The potential changes in water quality are small during the first phase of eutrophication and are not always detected with physical and chemical analyses (Hörnström 1981). In this situation phytoplankton identification and enumeration may yield much information and the results are valuable when observing changes and disturbances of aquatic ecosystems (Willen and Willen 1978). The use of phytoplankton as indicators gives also good information for eutrophication estimation, as has been recommended by many authors (Hellawell 1977). Unfortunately, at present, there is ability to explain or use only a tiny part of this information (Tikkanen 1986).

In discussion of phytoplankton analyses many means has been used like quotients and trophic systems, which are depending on the tendency of species or groups known to prefer some estimates like trophic level. In this paper is collected a short literature review of quotients, phytoplankton groups and species indicating the level of eutrophy.

2 P H Y T O P L A N K T O N A S A N I N D I C A T O R O F E U T R O P H Y

2.1 NUMBER OF SPECIES

In Finnish inland waters the number of species per sample variated from 3 to 160 according to research material sampled in 1963 and 1965 (Heinonen 1980). The median value of the species number in 1963 and 1965 were 54 and 62, respectively. The smallest numbers were recorded in waters polluted by industrial effluents and the highest were observed in eutrophic lakes affected by domestic wastes. The number of species have been observed to increase with increasing eutrophication at least to a biomass level of 2.0 mg l^{-1} (Eloranta 1978) or 5.0 mg l^{-1} (Heinonen 1980). When the biomass level is over 10 mg l^{-1} the species number decreases and biomass increases further (Heinonen 1980). The decrease of the number of species may

be in some cases an artefact. The sample taken from a very eutrophic water has to be diluted before microscopying and the part of original sample being studied is thus small. So the samples from oligotrophic and eutrophic waters may be incomparable because of different sample size (Eloranta 1978). Rawson (1956) noticed that in practice eutrophic lakes also seem to have many species but they are concentrated and restricted in trophogenic layer. In oligotrophic lakes plankton is distributied to greater depths.

2.2 BIOMASS

Phytoplankton volume and a-chlorophyll concentration have frequently been used as measures of the nutrient level in water bodies. Heinonen (1980) made a regional survey in Finnish inland waters of the quantity and composition of phytoplankton from 826 samples in midsummer 1963 and 1965. In 1963 the phytoplankton biomass varied between 0.01 and 45.0 mg l^{-1} and in 1965 between 0.02-18.6 mg l^{-1}. Of the lakes investigated 64.7 % were oligotrophic, 15.6 % in state of arising eutrophy and 8.9 % were clearly eutrophic.

The lakes were classified according to midsummer phytoplankton biomass concentrations:

Phytoplankton biomass (mg l^{-1}, fresh weight)	Classification
< 0.20	ultra-oligotrophic
0.21-0.50	oligotrophic
0.51-1.00	incipient eutrophy
1.01-2.50	mesotrophic
2.51-10.0	eutrophic
>10.0	hypereutrophic

Odour index, a new variable presented by Heinonen (1980) correlated strongly with phytoplankton biomass in this study.

Hörnström (1981) studied 332 lakes situated in southern Sweden. The samples were taken during the late summer period (1972-1976) from a depth of 0.5 meters. On the basis of this study Hörnström (1981) concluded that phytoplankton biomass and a-chlorophyll concentration describe the trophic state of lake better than nutrient concentrations.

2.3 ALGAL QUOTIENTS

The purpose of algal quotients is to indicate the trophic level by a simple numerical value calculated with a formula. The numerator is the number of species preferring eutrophy and the denominator is the total number of species preferring oligotrophy (Kostiainen 1965).

Many quotients have been presented, e.g. a Protococca-

les/Desmidiales quotient by Thunmark (1945) and blue-green algae quotient, diatom quotient and compound quotient by Nygaard (1949). Both have studied net samples consisting mainly of large species. Heinonen (1980) applied these quotients and found that they were not applicable to Finnish waters partly because of the lack of a single and entire algal order favouring a certain fixed trophic level. Rapid temporal changes in phytoplankton composition and in environmental conditions also decrease the applicability of quotients. Futher more the Swedish and Danish quotients are unsuitable for samples taken in different seasons (Niinioja 1975).

The quotient presented by Järnefelt (1952) depends on the ratio between the number (E/O) and volume (EV/OV). The E/O quotient is calculated from the numbers of species favouring eutrophic and oligotrophic environments, and EV/OV quotient from the total volumes of the same species. Järnefelt based his study on samples collected personally by him in the years 1930-1947. Samples were collected during June - October as net samples, directly to bottles or with a plankton sampler. The number of studied lakes was 329 and Järnefelt grouped them into four trophic classes, mostly on the basis of his own visual observations (Heinonen, pers. comm.). The assigment of species to eutrophy and oligotrophy indicators was based on their frequencies at occurrence in these four different trophic croups of lakes. The number of species indicating eutrophy were 90 (first class indicators) and 18 (second class indicators) and those indicating oligotrophy 13 (Appendix 1).

Järnefelt et al. (1963) presented the following classification.

A. Eutrophy indicators (E-species)
a. first class indicators:
   Species being at least four times more frequent in eutrophic waters than in oligotrophic waters.
b. second class indicators:
   Species being three times more frequent in eutrophic than in oligotrophic waters.

B. Oligotrophy indicators (O-species)
   The frequency coefficient 0.7.

When the quotient E/O reaches 8 or the value of their volumes (EV/OV) exceeds 35, the lake is classified eutrophic. Reliable indicators of oligotrophy are few (Järnefelt et al. 1963, Heinonen 1980) and it is difficult to find species for the denominator. According to Eloranta (pers. comm.) the ratios presented by Järnefelt should be further examined and the limits could be increased, E/O up to 15-20 and EV/OV up to 80-100. This is because of the development of optics used by microscopying. Taxonomy has also developed markedly since then.

Heinonen (1980) calculated the occurrence frequency

of each indicator species of Järnefelt et al. (1963) for each eutrophication group based on phytoplankton biomass concentration. The species, which commonly occurred in eutrophic lakes, but were absent or rare in oligotrophic lakes were considered as indicators of eutrophy. Most of the oligotrophic indicators were, however, found quite frequently in eutrophic waters too. Heinonen (1980) proposed 21 new eutrophy indicators and 10 species indicating oligotrophy (Appendix 2).

Hörnström (1981) has made an attempt to developed a simple biological method for determination the trophic status of lakes. The trophic species index was calculated from the median value of the total phytoplankton volumes and the trophic index was assigned to each species identified and counted. The index varied from 11-100, where 11 was the most oligotrophic and 100 the most eutrophic one. Number 33 implies already oligotrophy in this study. For detailed information of species and their index number, see appendix 3.

2.4 ALGAL GROUPS AND SPECIES

In general Cyanophyta, Chlorophyta, Euglenophyta and Heterocontophyta (e.g. centric diatoms) prefer eutrophic conditions. On the other hand Chrysophyta and some desmids prefer oligotrophy. However, there are species within these groups which have very different environmental requirements, some preferring eutrophy and a smaller fraction preferring oligotrophy (Järnefelt et al. 1963).

Rawson (1956) found numerous difficulties in using groups, generas and species as indicators in great Canadian oligotrophic lakes. Blue-green algae were scarce as excepted but so were desmids, considered as characteristic of oligotrophy. Usually diatoms indicating eutrophy were dominant. *Dinobryon*, considered by some authors as oligotrophic indicator, was common but rarely dominant.

On the other hand the biomass of Euglenophyta were found to be low in oligotrophic waters and even a small increase of these organisms indicated eutrophication or pollution (Heinonen 1980).

Mantere (1981) examined the occurrence of green algae in different waters. The material, at 72 samples from 15 sampling sites, was collected from the depth of 0-2 m in June, July and August 1971 and 1977 from the Vuoksi water course in eastern Finland. The area studied was grouped into oligotrophic waters, eutrophic waters, waters loaded with municipal nutrients and waters polluted by pulp and paper industry. With increasing eutrophy the number of species of chlorococcales and desmidiales increased, the quantity and diversity of different species, in particular, of *Scenedesmus* and *Pediastrum*, also increased. According to Mantere (1981) the only species indicating oligo-

trophy in this study was *Arthrodesmus incus* (Breb.) Hass (*Staurodesmus incus*). In Table 1 are presented some species found in eutrophic waters.

Table 1. Some species found in naturally eutrophic waters and waters loaded by municipal nutrients (Mantere 1981).

Species
Chlamydomonas sp.
Closterium gracile Brebisson
Kirchneriella contorta (Schmidle) Bohlin
Micractinium pusillum Fresenius
Pediastrum duplex Meyen
P. tetras (Ehrenb.) Ralfs.
P. boryanum (Turp.) Menegh.
Scenedesmus armatus Chod.
S. bicellularis Chod.

Lepistö (1988) studied the occurrence of Eupodiscales (centric diatoms) in different waters. Altogether 79 samples were taken in July 1986 as profile samples from the surface to the depth of 2 meters. The lakes studied were grouped into the following categories: oligotrophic lakes, naturally eutrophic lakes, lakes made eutrophic by nutrients and waters polluted by pulp and paper industry. Four humic lakes and two reservoirs were included. Centric diatoms are known to prefer eutrophy (Sladezek 1986). In addition to the centric diatoms in the list of indicator species of Järnefelt et al.(1963), two species could be shown to indicate eutrophy. *Melosira ambigua* (Grun.) Müller (*Aulacoseira ambigua*) and *Attheya zachariasii* Brun (*Acanthoceros zachariasii*) were found particularly in lakes eutrophied with nutrients. *Melosira tenella* Nygaard (*Aulacoseira tenella*) clearly preferred humic lakes and waters polluted by pulp and paper industry.

A relation between some phytoplankton species or groups has also been used when studying environmental chances. Granberg (1973) used *Cryptomonas / Rhodomonas*- index when studying the influence of wastewaters from pulp and paper industry to the water quality and on other hand *Melosira distans / Melosira italica*-index in studies of eutrophy (Granberg 1970). Phytoplankton blooms are often caused by blue-green algae, especially in eutrophic conditions by gas vacuolate Cyanophyta (Round 1981). Some of the bloom forming species are known to be able to produce toxins. Sivonen et al. (1990) studied the toxicity of the species of the blue-green algae forming blooms and found that 45 % of the species were hepatotoxic or neurotoxic (Table 2). Hepatotoxic blooms were almost twice as common as neurotoxic blooms in Finnish fresh waters during 1985 and 1986.

Table 2. Toxic blue-green species in Finnish lakes with 95 % significance (*); 99 % significance (**); 99,9 % significance (***) in chi-square analysis. Species without asterisks were not significantly more frequent in toxic than nontoxic blooms (Sivonen et al. 1990).

Species	Hepatotoxic	Neurotoxic
Anabaena lemmermannii		***
Anabaena spiroides	**	
Anabaena flos-aquae	*	**
Anabaena solitaria		
Anabaena circinalis		
Microcystis wesenbergii	**	
Microcystis viridis	***	
Microcystis aeruginosa	***	
Gomphosphaeria naegeliana		*
Oscillatoria agardhii		
Aphanizomenon flos-aquae		

3 C O N C L U S I O N

The composition of phytoplankton of various waters shows certain general characterics which is possible to indicate with phytoplankton indices.

The suitability of various algal groups, algal species and quotients as indicators of eutrophy have been tested. It is typical of algae, that they all flourish in eutrophic conditions. No algal species flourish in oligotrophic conditions, but there are some that survive. Indicator species are often unsatisfactory, because they occur in different waters, and only few species can be found only in oligotrohic lakes (Heinonen 1980, Mantere 1981). Rawson (1956) did not find indicators of oligotrophy and pointed out that they may not even exist.

The basic idea of the quotients is, that different taxa prefer oligotrophy or eutrophy. Most of the quotients are shown to be suitable only to relatively limited geographical areas.

The occurrence of different groups may depend more on the season of the year, pH-value, humus content or conductivity rather than on the trophic level of the lake. To clarify these correlations, more investigations of the indicator species are needed, e.g. by frequent sampling in different seasons, by controlled laboratory experiments of eutrophication and by comparing these results to environmental parameters. Attention should also be given to other algal communities and their indicator value in water ecosystems.

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A. Phytoplankton species indicating eutrophy (Järnefelt et al. 1963)

a. 1-class indicators	Synonyms
Actinastrum hantzschii	
Amphiprora spp.	
Anabaena circinalis	
" planctonica	Anabaena solitaria Klebahn
" spiroides	
Aphanizomenon gracile	Aphanizomenon flos-aquae f. gracile (Lemm.) Elenkin
Arthrodesmus convergens	Staurodesmus convergens (Ehr.) Teiling
" octocornis	
Asterionella gracillima	Asterionella formosa Hassall
Centritractus spp.	
Chroococcus dispersus	
Closterium gracile	
Coelastrum cambricum	
" reticulatum	
Cosmarium humile	
" punctulatum	
" regnellii	
" regnesii	
Dimorphococcus lunatus	
Euastrum bidentatum	
Eudorina charkowiensis	Pandorina charkowiensis Korshikov
Euglena acus	
" oxyuris	
Fragilaria capucina	
" crotonensis	
Gonium pectorale	
Kirchneriella contorta	
" elongata	Kirchneriella contorta v. elongata (G.M.SM.) Komárek
" lunaris	
" obesa	
Lagerheimia spp.	
Lepocinclis spp.	
Lyngbya contorta	
Melosira granulata	Aulacoseira granulata (Ehr.) Simonsen
" islandica	Aulacoseira islandica (O. Müll.) Simonsen
" varians	
Micractinium pusillum	
Microcystis aeruginosa	
" elabens	Aphanothece elabens (Bréb.) Elenkin
" flos-aquae	Microcystis aeruginosa Kützing
" pulverea var. incerta	Microcystis reinboldii (Richter) Forti
" viridis	
Nephrocytium limneticum	
Oocystis solitaria	
Ophiocytium spp.	
Oscillatoria limnetica	
Pediastrum araneosum	Pediastrum angulosum (Ehr.) ex Meneghini
" duplex	
" gracillimum	Pediastrum duplex v. gracillimum W. & G.S. West
" limneticum	Pediastrum duplex Meyen
" tetras	

Peridinium bipes	
" umbonatum	
" volzii	
Phacus longicauda	
" pleuronectes	
Phacus spp.	
Scenedesmus abundans	Scenedesmus subspicatus Chodat
" acutiformis	
" armatus	
" " var. bicaudatus	Scenedesmus semipulcher Hortobágyi
" carinatus	Scenedesmus opoliensis v. carinatus Lemmermann
" denticulatus	
" falcatus	
" fenestratus	Scenedesmus denticulatus Lagerheim
" longus	Scenedesmus dispar (Bréb.) Rabenhorst
" naegelii	
" opoliensis	
Selenastrum bibraianum	
Sphaerozosma granulatum	Teilingia granulata (Roy & Bisset) Bourrelly
Staurastrum avicula	
" paradoxum var. parvum	
" tetracerum	
Stephanodiscus dubius	
Synedra berolinensis	
Synura uvella (identification?)	Synura petersenii Korshikov
Tetraëdron caudatum	
" limneticum	Pseudostaurastrum limneticum (Borge) Chodat
" planctonicum	Pseudostaurastrum planctonicum (G.M.SM.) Chodat
" regulare	Tetraedriella regularis (Kützing) Fott
" trigonum	Goniochloris fallax Fott
Tetrastrum spp.	
Trachelomonas abrupta	
" acanthostoma	
" armata	
" kelloggii	
" oblonga	
Trachelomonas varians	
Westella botryoides	
Volvox aureus	

b. 2-class indicators	Synonyms
Closterium venus	
Coelastrum microporum	
Cosmarium meneghinii	
Cyclotella meneghiniana	
Dictyosphaerium ehrenbergianum	
" elegans	
Euglena spp.	
Glenodinium gymnodinium	
Nephrocytium lunatum	
Pandorina morum	
Pediastrum boryanum	
Scenedesmus arcuatus	
" hystrix	
Staurastrum dejectum	Staurodesmus dejectus (Bréb.) Teiling
Synedra acus	
Tetraëdron spp.	

Trachelomonas hispida	
" volvocina	
B. Oligotrophy indicators	Synonyms
Arthrodesmus incus	Staurodesmus incus (Bréb.) Teiling
Chroococcus turgidus	
Crucigenia irregularis	Willea irregularis (Wille) Schmidle
Cyclotella kützingiana	
Dactylococcopsis smithii	
Diceras spp.	Bitrichia sp.
Dinobryon bavaricum	
" cylindricum	
" divergens	
Kephyrion spp.	
Mallomonas allorgei	
Merismopedia glauca	
Stichogloea olivacea	

Indicator species (Heinonen 1980)

A. Phytoplankton species indicating eutrophy	Synonyms
Actinastrum hantzschii Lagerheim	
Amphiprora paludosa W. Smith	
Ankistrodesmus falcatus v. spirilliformis West	Monoraphidium contortum (Thuret) Kom.-Leg.
Characiopsis longipes (Rab.) Borzi	
Chroococcus dispersus (Keissl.) Lemm.	
Chrysococcus minutus (Fritsch) Nyg.	
Closteriopsis longissima Lemm.	
Closterium aciculare T. West	
C. gracile Bréb.	
C. macilentum Bréb.	
C. pronum Bréb.	
Coelastrum cambricum Archer.	
Diatoma elongatum (Lyngb.) Ag.	
Dictyosphaerium ehrenbergianum Naeg.	
D. elegans Bachman	
Dimorphococcus lunatus A.Br.	
Euglena acus E.	
E. charkowiensis Swir.	
E. proxima Dang.	
Franceia ovalis (Francé) Lemm.	
Glenodinium gymnodinium Penard	
Kirchneriella elongata G.M. Smith	Kirchneriella contorta v. elongata (G.M.SM.) Komárek
K. lunaris (Kirchn.) Moebius	
K. obesa (W. West) Schmidle	
Lagerheimia genevensis Chod.	
Lepocinclis texta (Duj.) Lemm. em. Conr.	
Lyngbya limnetica Lemm.	
Melosira granulata (E.) Ralfs.	Aulacoseira granulata (Ehr.) Simonsen
M. varians C.A. Agardh	
Micractinium pusillum Fresenius	
Microcystis aeruginosa Kg.	
M. flos-aquae (Wittr.) Kirchn.	Microcystis aeruginosa Kützing
M. viridis (A.Br.) Lemm.	
Nitzschia acicularis W.Sm.	
Oscillatoria limnetica Lemm.	
Pandorina morum (Müller) Bory.	
Pediastrum biradiatum Meyen	
P. duplex Meyen	
P. gracillicum (W. et G.S. West) Thunmark	Pediastrum duplex. v. gracillimum W. & G.S. West
P. limneticum Thunmark	Pediastrum duplex Meyen
P. tetras (Ehrenb.) Ralfs.	
P. tetras v. tetraodon (Corda) Rabenhorst	Pediastrum tetras (Ehr.) Ralfs
Peridinium bipes Stein	
P. penardiforme Lindem.	
Phacus curvicauda Swir.	
P. longicauda (E.) Duj.	
P. tortus (Lemm.) Skv.	
Polyedriopsis spinulosa Schmidle	
Scenedesmus abundans (Kirchn.) Chod	
S. armatus v. bicaudatus (Guglielmetti-Printz) Chod	
S. falcatus Chod.	
S. naegelii Breb.	
S. opoliensis P. Richt	
S. ovalternus v. graewenitzii (Bernard) Chod.	

Selenastrum gracile Reinsch	
Sphaerozosma granulatum Roy et Biss.	Teilingia cranulata (Roy & Bisset)
Staurastrum paradoxum v. parvum West	
Strombomonas verrucosa (Daday) Defl.	
Synedra berolinensis Lemm.	
Tetraedron caudatum (Corda) Hansgirg.	
T. limneticum Borge	Pseudostaurastrum limneticum (Borge) Chodat
T. planctonicum G.M. Smith	Pseudostraurastrum planctonicum (G.M.SM.) Chodat
T. trigonum (Naeg.) Hansgirg.	Goniochloris fallax Fott
Tetrastrum staurogeniaforme (Schroeder) Lemm.	
Trachelomonas hispida (Perty) Stein em. Defl.	
T. intermedia Dang.	
T. planctonica Swir.	
T. varians Defl.	
T. volvocina E.	
T. volvocinopsis Swir.	

B. Phytoplankton species indicating oligotrophy	Synonyms
Arthrodesmus incus (Bréb.) Hass.	Staurodesmus incus (Bréb.) Teiling
Cosmarium contractum Kirchn.	
Crucigenia rectangularis (A. Braun) Gay	Crucigeniella rectangularis (Näg.) Komárek
Diatoma vulgare Bory	
Dinobryon acuminatum Ruttn.	
D. cylindricum Imh.	
D. sertularia E.	
Euastrum bidentatum Näg.	
E. elegans (Breb.) Kütz	
Mallomonas akrokomos Ruttn.	
M. allorgei (Dofl.) Conr.	
Nephrocytium limneticum (G.M. Smith) Skuja	
N. lunatum W. West	
Quadrigula lacustris (Chod.) G.M. Smith	
Stichogloea doederleinii (Schmidle) Wille	

Phytoplankton species and their trophic index values calculated from the medium value of the total phytoplankton volumes (Hörnström 1981).

	Trophic index	Synonyms
Microcystis spp.	100	
Aphanizomenon flos-aquae Ralfs	100	
Phacus spp.	98	
Melosira granulata (Ehr.) Ralfs	95	Aulacoseira granulata (Ehr.) Simonsen
Ankistrodesmus spp., Coelastrum spp.	90	
Anabaena planctonica (Brunnth.) Kom.		Anabaena solitaria Klebahn
Anabaena spiroides (Lemm.) Elenk.	85	
Staurastrum paradoxum var. parvum W. West		
Staurastrum pingue Teil.		
Staurastrum smithii (G.M. Smith) Teil.	68	
Tetraedron trigonum var. gracile	60	
Gonyostomum semen (Ehr.) Dies.	55	
Pediastrum boryanum (Turp.) Menegh.		
Pediastrum duplex Meyen	55	
Trachelomonas spp.	55	
Attheya zachariae Brunnth.		Acanthoceras zachariasii (Brun) Simonsen
Fragilaria crotonensis Kitt	51	
Tetraedron caudatum (Corda) Hansg.	51	
Synura spp.	50	
Peridinium bipes Stein		
Peridinium cinctum (O.F.M.) Ehr.		
Peridinium willei Huith.-Kaas	50	
Closterium acutum var. variabile (Lemm.) Krieg.	50	
Melosira ambigua (Grun.) O. Müll.	46	Aulacoseira ambigua (Grun.) Simonsen
Pediastrum tetras (Ehr.) Ralfs	40	
Chrysosphaerella longispina Laut.	40	
Synedra acus Kütz.	40	
Dinobryon divergens Imh.	39	
Gymnodinium fuscum Stein.	35	
Dictyosphaerium pulchellum Wood	35	
Asterionella formosa Hass.	34	
Ceratium hirundinella (O.F.M.) Schrank	34	
Oscillatoria agardhii Gom.	34	
Staurodesmus cuspidatus var. curvatus (C.W.West) Teil.	34	
Tetraedron minimum (A. Br.) Hansg.	33	
Gomphosphaeria naegeliana (Ung.) Lemm.	33	
Rhizosolenia longiseta Zach.	33	
Dinobryon cylindricum var. palustre Lemm.	33	
Dinobryon bavaricum Imh.	31	
Uroglena americana Calk.	31	
Tabellaria fenestrata (Lyngb.) Kütz	29	
Chrysochromulina parva Lack.	27	
Spondylosium planum (Wolle) West & West	26	
Staurodesmus mamillatus (Nordst.) Teil.	25	
Gomphosphaeria lacustris Chod.	25	
Melosira distans var. alpigena Grun.	23	Aulacoseira distans v. alpigena (Grun.) Simonsen
Chrysidiastrum catenatum Lauterb.	21	
Quadrigula spp.	21	
Dinobryon suecicum Lemm.	21	

	Trophic index
Crucigenia tetrapedia (Kirch.) West & West	21
Dinobryon borgei Lemm.	20
Staurastrum anatinum Cooke & Wills	
Staurastrum longipes (Nordst.) Teil.	20
Staurodesmus extensus (Borge) Teil.	19
Anabaena flos-aquae Bréb.	18
Elakatothrix spp.	17
Monoraphidium dybowskii (Berkel) Kom.-Legn.	16
Stichogloea doederleinii (Schmidle) Wille	15
Staurodesmus sellatus	15
Gymnodinium uberrimum (Allm.) Kof. & Swezy	14
Sphaerocystis schroeterii Chod.	14
Willea irregularis (Wille) Schmidle	14
Dinobryon crenulatum West & West	13
Chroococcus limneticus Lemm.	12
Peridinium inconspicuum Lemm.	12
Kephyrion boreale Skuja	12
Aphanothece ellipsoidea (Schröd.) Bourr.	12
Bitrichia chodatii (Rev.) Chod.	12
Monoraphidium griffithii (Berkel) Kom.-Legn.	12
Oocystis submarina Lagerh.	11
Merismopedia tenuissima Lemm.	11
Istmochloron trispinatum (West & West) Skuja	11

REPORT ON NUISANCE ALGAE EMERGING RECENTLY IN EASTERN FINLAND

Jarmo Kivinen
The Water and Environment District of Mikkeli
PB 77, SF-50101 Mikkeli, Finland

1 A B S T R A C T

In the 1980's, two algae that belong taxonomically to different groups have generated exceptionally dense populations causing public alarm starting from Eastern Finland.

The first to be detected was *Gonyostomum semen* (Ehrenb.) Dies. *Raphidophyceae* in the early 1980's, causing slimy irritating coating on swimmers mainly in humic dark water lakes. There have also been new findings in southern and central Sweden and east-west Norway on *Gonyostomum semen* in recent years.

Secondly there have also been many observations on severe gill net sliming caused by desmid *Hyalotheca dissiliens* in the 1980's. Sliming may be so strict that the net is thoroughly covered with dense green slime. The alga mostly dwells in large oligohumic, oligothrophic lakes.

Data of worldwide distribution and some preliminary results on ecology will be given of both species.

2 I N T R O D U C T I O N T O *G O N Y O S T O M U M S E M E N*

Gonyostomum semen (Ehrenb.) Dies. is a unicellular flagellate with two flagellas (Fig. 1). The cells are large (length 50 - 100 µm, breadth 20 - 24 µm and width 10 - 25 µm) oval, dorsoventrally flattened and have a shiny yellow-green colour.

Gonyostomum lacks a real cell wall and is therefore very fragile. Inside the cell membrane there are hundreds of discoid chloroplasts and slime bodies (thrichocysts).

The ultra structure of the *Gonyostomum* cells has been thoroughly studied and reviewed by Heywood. *Gonyostomum* can grow in culture if a soil-peat medium or chloromonad medium with vitamins (B_{12}, biotin, thiamine) is used (Heywood 1973). In less favourable conditions in nature, *Gonyostomum* survives as spherical cysts deposited on sediment surface. When active the presence of trichocysts inside the *Gonyostomum* cells contributes to a specific mode of action when stimulated by chemicals, heat, or physical contact. The trichocysts explode and slime treads that can be up to 200 µm long are thrown out. With gentle stimulation only few trichocysts break, but with strong stimulation all

trichocysts explode and the cell is destroyed.

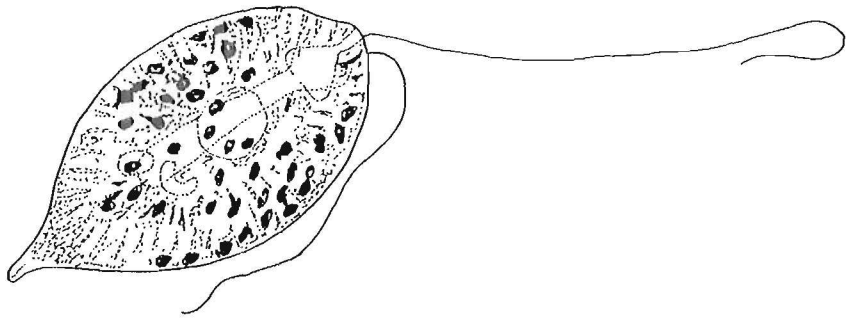

Fig 1. *Gonyostomum semen*

When preserving phytoplankton samples in formalin the cells of *Gonyostomum* are destroyed and can hardly be recognized but *Gonyostomum* can be preserved in Lugol's solution without serious damage to the cells. A high concentration of *Gonyostomum* in a water body can be immediately recognized when sampling with a plankton net. The net becomes clogged and slimy due to broken trichocysts.

Gonyostomum semen was first described by Ehrenberg under the name *Monas semen* from a small pond outside Berlin. Diesing (1865) changed the name to *Gonyostomum semen*. Levander (1894) recorded *Gonyostomum* for the first time in Finland in a small pond outside Helsinki.

The first mass development of *Gonyostomum* in a larger lake causing public alarm occurred in 1948 in Lake Helgasjön, Sweden (Sörensen 1954). People swimming in the lake complained about a brownish slimy layer on their bodies, causing itching and allergic reaction. This slimy layer was shown to be broken cells of *Gonyostomum*.

Lately it has been shown that *Gonyostomum semen* has a worldwide distribution, including Sweden, Norway, Denmark, Finland, Austria, Czechoslovakia, USA, Canada, and South America (Bourrelly 1970) and Africa (Gerroth and Denny 1980).

It was assumed in many earlier works that *Gonyostomum* favours acid water (Fott 1968, Drouet and Cohen 1935, Skuja 1948, and Nygaard 1977). The latest author has observed that *Gonyostomum* is common in places with a pH value of 3.7 - 4.6 and rare in pH 5 - 6 and that it is often found in small acid lakes and peat bogs with brown and constantly acid water.

Sörensen (1954) describes *G. semen* as an inhabitant of the plankton flora of quite large lakes with pH values between 6.3 - 7.0. Rosen (1981) also states that the data of a large lake survey in Sweden in 1972 is in

accordance with Sörensen, *G. semen* was not found in lakes with pH below 5 and the maximum was 7.7 and the median value 6.6. The data were based on 166 lakes with an area of more than 10 hectares. Rosen states that *G. semen* is pH-tolerant and former figures given by earlier investigators are of little value.

Cronberg et al. (1988) linked G. semen not directly to pH-values but to the consequences of acid precipitation. *G. semen* seems to be dependent on humus or other organic material. In Rosen's (1981) material the median of water colour was 60 mg l^{-1} Pt and Sörensen connected *G. semen* in one lake with organic substances from a pulp mill. Eloranta and Palomäki (1986) found *G. semen* in a lake that was the recipient of a fish farm effluent.

According to Rosen (1981) great volumes of *G. semen* are mostly found in water bodies with a phosphorus-concentration of more than 20 µg l^{-1}. Gronberg et al. (1988) also found that there was a very close correlation between "*Gonyostomum* biomass" and total phosphorus ($r = 0.84$; $n = 14$) and the correlation between total P and lake a chlorophyll was also clear ($r = 0.85$; $n = 24$).

3 STUDIES IN THE WATER AND ENVIRONMENT DISTRICT OF MIKKELI

Because the upburst of *Gonyostomum* coincide with the expansion of peat extraction in Lake Kangasjärvi region there was a wide public opinion that peat extraction was the cause of the dense *Gonyostomum* population.

At that time a national project of water pollution consequences of peat extraction was launched. A hypothesis that peat extraction was the cause of *Gonyostomum semen* upburst in Lake Kangasjärvi and smaller lakes also under the influence of peat extraction was included in the project.

In a nearby area the problems and public alarm caused by the dense *Gonyostomum* population were studied in accordance to the Lake Kyyvesi water pollution protection plan.

3.1 METHODS

G. semen samples were taken as 0 - 2 m composite samples according to the depth of the lake. Some samples from very small lakes were taken directly from the shore to a one litre plastic bottle.

In the laboratory samples were settled down in the counting chamber for ten minutes. Although *Gonyostomum* is capable of moving, it was found that in that time

nearly all individuals remained motionless at the bottom.

Sparse samples were centrifuged at a rotating speed of 400 r min^{-1} in 40 ml centrifuge tubes for some minutes. The speed was safe for fragile cells. The bottom part was removed with a Pasteur-pipette to a counting chamber. In both cases cells were counted by inverted microscope either by random sampling (dense samples) or by counting the whole bottom area (sparse samples).

Physio-chemical analysis were conducted by Finnish standard (SFS) methods.

4 MAIN RESULTS WITH CONCLUDING REMARKS

It was confirmed that the occurrence of a dense *Gonyostomum* population is not directly connected with peat extraction. There were also quite dense *G. semen* populations in lakes that were not connected with drainage water from peat extraction areas. In Lake Löytynlampi, the quantities were quite comparable with those of Lake Kangasjärvi, for example (Table 1).

Table 1. *Gonyostomum semen* in most intensively studied-lakes. + = some individuals. Results are given as wet weight mm^3 l^{-1}.

Name	Peat extraction influence (+)	19.-20.6. 1984	3.-4.7. 1984	24.-25.7. 1984	15.8. 1984	4.-5.9. 1984
Lake Kangasjärvi	+	1.0	2.2	8.7	6.6	1.7
Lake Heiniönlampi	+	0	0	+	1.4	0
Lake Höytiönlampi	+	0	0	0	0	+
Lake Löytynlampi	-	1.5	4.0	7.7	0.11	0.7
Lake Haukilampi	-	0	0	0	0	0
Lake Pitkäjärvi	-	0	0	0	0	0
Lake Viranlampi	-	0	0	0	0	0

In Table 2 it is clearly seen the lakes studied are humic, with low conductivity, and with pH values near 6.0 as it was anticipated on the basis of the Swedish results and older data. It is also seen that water properties in lakes with *G. semen* findings did not differ greatly from the lakes without *Gonyostomum*. One can see that only total phosphorus concentrations are clearly higher in the *Gonyostomum* group, and also a-chlorophyll as a consequence of *Gonyostomum* populations. Good correlation between a-chlorophyll and *Gonyostomum* biomass can be seen from the results of Lake Löytynlampi in 1984 (Fig. 2).

Table 2. Mean ($\bar{x}$) and median (MD) values of selected physio-chemical parameters of studied lakes with and without *G. semen*.

		Lakes with G. semen			Lakes without G. semen		
		n=27	$\bar{x}$	Md	n=24	$\bar{x}$	Md
Conductivity	mS m^{-1}		4.2	4.2		4.0	4.2
pH			6.3	6.3		5.8	6.0
Colour	mg l^{-1} Pt		160	110		130	120
COD_{Mn}	mg l^{-1} O_2		21.8	17.0		19.4	16.5
Total P	µg l^{-1}		48	40		30	23
Total N	µg l^{-1}		720	600		590	550
Fe	µg l^{-1}		1350	850		900	700
a-chlorophyll	µg l^{-1}		35.9	31		10.0	6.5

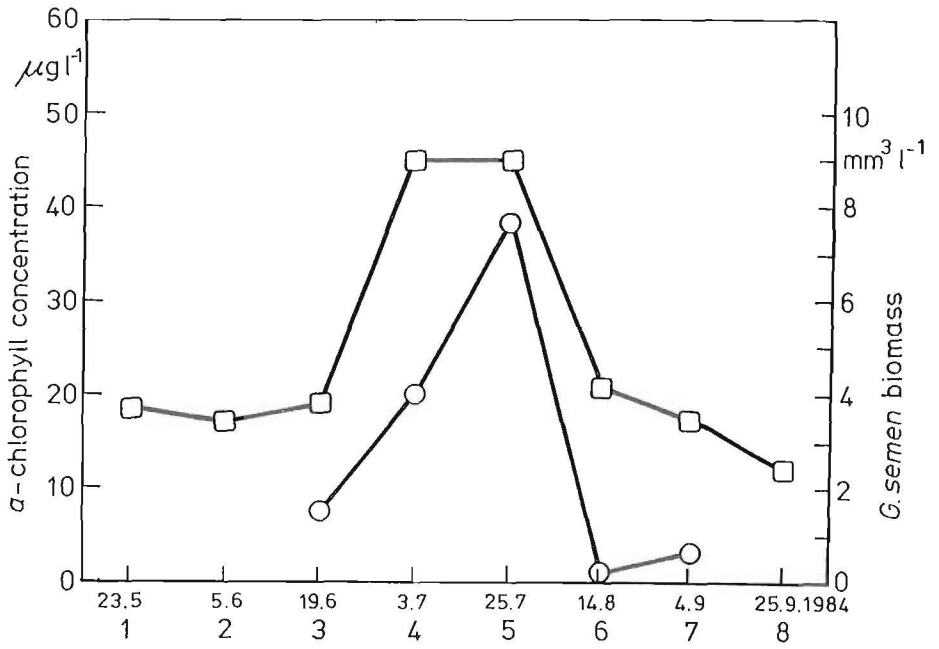

Fig. 2. *Gonyostomum semen* -biomass and a-chlorophyll in Lake Löytynlampi. x-x = a-chlorophyll o-o = *Gonyostomum semen*.

Gonyostomum semen is so large an alga with large chloroplasts that its share of the whole biomass is mostly dominant even up to more than 90 per cent.

In Lake Kyyvesi, a lake of 137 km^2 situated 10 km to the west of Lake Kangasjärvi, phytoplankton biomass samples have been gathered at about 4 years intervals from the 1960's up to the present (Fig. 3).

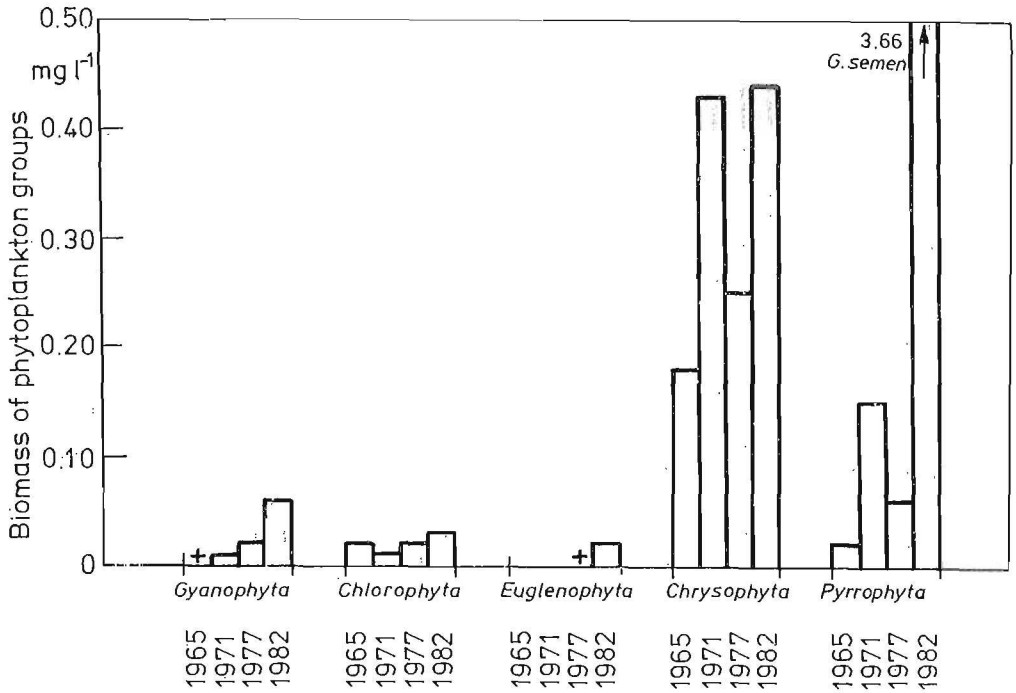

Fig. 3. Biomass of the main phytoplankton groups in Lake Kyyvesi during the period 1965 - 1982, wet weight mg l^{-1}.

In Figure 3 it is seen that the only dramatic event was the upburst of *Gonyostomum semen* in the plankton flora in 1982. It did not occur as a consequence of clear decrease in other groups, and there were no very marked differences in the measured physio-chemical parameters during the time. Therefore it is quite probable that *Gonyostomum semen* takes advantage of heterotrophic capabilities at the same time as it gains autotrophic energy by photosynthesis.

One possible explanation for its occurrence is the eroding and dissolving capacities of acid precipitation. The latest decennium was according to the latest hydrological data one of the wettest during the observation period. It is also true that study areas in eastern or south-eastern Finland get quite an atmospheric load in the national framework. The pH of the rain and melting snow is about 4.5 and occasionally below 4.0. So one can link the upburst of *Gonyostomum semen* to the acid precipitation also in Finland as Cronberg et al. (1988) did in Sweden. The mechanism of the exceptional growth can be the dissolving of trace metals or even vitamins (Heywood 1975) to discharging waters. This hypothesis needs intense further studies.

5 INTRODUCTION TO *HYALOTHECA DISSILIENS*

Hyalotheca dissiliens (Smith) Brebisson belongs to *Desmidiales* algae. Cells of the alga are about 1/4 broader compared with the length, with a narrower part in the middle of the cell.

The length of the alga varies from 10 to 33 µm and it is 10 - 39 µm broad. The length of the cell varies more than the breadth and it is irregular and not connected with seasons (Ohtani 1985). There are two longitudinal chloroplasts in the cell situated in their own parts of the cell.

The cells are connected to filamentous cell chains and these chains are mostly covered with a thick slimy coating (Fig. 4).

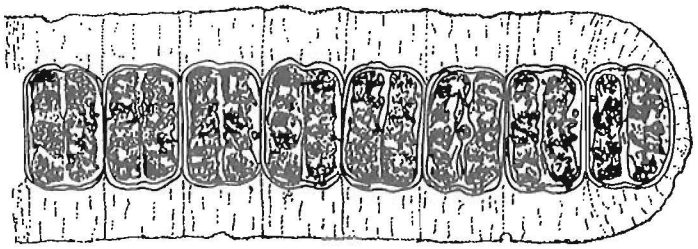

Fig. 4. Cell chain of *Hyalotheca dissiliens* with typical slime coating.

There are various morphological forms of *Hyalotheca dissiliens*. For instance there is var. *minor* Delp. (West and West 1971) the filaments of which are usually naked cells nearly as broad as long or slightly broader. The lenght of the cells is 18 µm, the breadth 21 µm. The more common form is var. *major* Delp. Filaments are usually covered with a sheath, cells 1.3 times broader than long or even still broader. The length of a cell is 27 µm and the breadth 36 µm. West and West (1971) state that sheathless forms of *Hyalotheca dissiliens* do not commonly occur.

The vertical view of the species varies in appearance and in consequence of this several forms are recognized. The typical form has an exactly circular vertical view; without projections of any kind, and it is known as form *circularis*. There are also forms *bidentula* Nordst. and *tridentula*. There is nowadays tendencies to divide *Hyalotheca dissiliens* as separate species (Harri Kousa, pers. comm.).

Hyalotheca dissiliens is quite a cosmopolitan. According to West and West (1971) it was found outside the British Isles; nothern, southern and central Europe; nothern, southern and central Russia; Nova Zemlja, Spitzbergen, Greenland, Siberia, central China, India, East Indies, Australia, Africa, and North and South America.

There is not much specific ecological information of *H.dissiliens* in the literature. In the older litterature it is described to be an inhabitant of small water bodies. For instance West and West (1971) state that *H. dissiliens* is one of the most ubiquitous of Desmids and often occurs in great abundance. It is generally distributed in bogs and ditches but may also be planktonic.

Streble and Krauter (1973) also gave bogs and drainage ditches as the main biotopes of *Hyalotheca dissiliens*. An up-to-date Finnish manual by Tikkanen (1986) states that *Hyalotheca* species found in Finland are typical in brown small water bodies or in the littoral zone of waterbodies but may even be planktonic.

As a rule it is like other desmids traditionally associated with quiet standing waters such as mildly acidic lakes and bogs of low conductivity and a high humic acid content (West and West 1909, Taft 1945, Rawson 1956, Brook 1959, Hutchinson 1967, ref. Burkholder and Sheath 1984). Rosen (1981) also states that desmids are as a rule regarded as benthic algae and they are often found in great quantities in bog waters. Hallgrimsson (1976) found that *H. dissiliens* is common in neutral or slighly acid lakes in north-western, northern, and eastern Iceland. There is no information of the size of the lakes studied.

There are also findings of *H.dissiliens* in streams and rivers. Burkholder and Sheath (1984) found it present in a soft water, a northern temperate head water stream in USA, and Parra (1975) in river Rio Andalien in Chile.

6 STUDIES IN THE WATER AND ENVIRONMENT DISTRICT OF MIKKELI

Our studies began as a consequence of wide public alarm concerning sliming of fishermens' gill nets. Nets that had been in a lake one night were so thickly covered with bright green slimy material that it was said to be nearly impossible to raise nets up for fish catch examination. Former findings had mostly occurred in September-October when the lake water temperature was about 4-10 C°. The slimy material was identified as *H. dissiliens* filaments. The first literature consulted stated that *H.dissiliens* is an alga of peat bogs and drainage ditches. The study lake, Lake Ryökäsvesi of 20 km^2 situated 20 km southwest from Mikkeli, is large and clear-watered. Therefore we wanted to study where *H.dissiliens* was coming from to the nets.

6.1 METHODS

In the beginning normal epilimnic plankton samples with a 1 m-tube sampler or Ruttner-type sampler were taken. Because of the benthic habit of dwelling of *H.dissiliens*, we started in 1986 an one summer study of the littoral zone with coincide observation of small, 0.5 m x 0.5 m study nets with 15 mm mesh size. The nets were anchored to the depth of 1m from the surface and 3 m from the bottom, and they were incubated during 24 hours both on sheltered and open beaches. Periphytic growth was also studied both on sheltered and open beaches on 3 polycarbonate plates, size 10 cm x 15 cm. Incubation time was three weeks and the study period lasted from July 9th to August 13th.

Littoral samples were taken both from stones and macrophytes at the depth of 0.7 m. Periphyton on macrophytes was studied by brushing plants with a tooth brush. We tried to get comparable quantities by counting the quantity and the length of the stems. The quantities on the stone samples were made comparable with the following procedure: a stone with about 1 dm plain side was taken, then it was raised carefully to the surface, put in the plankton net and brushed the algae on the selected side to the net. The contents of the net were then removed to a bottle and diluted to 500-1000 ml, and the brushed area on the stone was measured by a transparence plate with measuring squares. The quantity of *H.dissiliens* was counted by inverted microscope using as counting unit the part of a filament that could be seen in one field of view (about 60-80 cells).

7 MAIN RESULTS WITH CONCLUDING REMARKS

On open beach periphyton plates there were $110 \cdot 10^3$ *H.dissiliens* cells during the period 24.7.-13.8. On other samples there were no cells. In the eight plankton samples taken there were no *H.dissiliens* cells. The results of cells found on macrophytes are presented in Table 3.

Table 3. *H.dissiliens* cells in periphyton on littoral macrophytes.

Site	Time	Species	Total length of shoots (cm)	Hyalotheca cells/2 ml
Sheltered 1	24.6.	Equisetum	10 x 20	0
Open 1	16.7.	Equisetum	10 x 20	0
Open 1	16.7.	Equisetum	10 x 20	0
Sheltered 2	24.7.	Phragmites	5 x 20	17
Open 1	11.8.	Equisetum	5 x 20	665
Sheltered 2	11.8.	Phragmites	5 x 20	38
Sheltered 2	11.8.	Lobelia	5 x 20	210
Sheltered 1	11.8.	Lobelia	5 x 20	12 700
Sheltered 1	13.8.	Lobelia	5 x 20	768
Open 2	13.8.	Lobelia	5 x 20	4 130

It is clearly seen that there were no *Hyalotheca* cells in the early summer samples and that cells are the most abundant in samples taken in August. Variation is also quite marked in nearby samples.

Results of the stone surface samples are found in Table 4.

Table 4. *Hyalotheca dissiliens* cells on littoral stones.

Site	Time	Depth m	Number of Hyalotheca cells 1 000 per m^2
Open 2	23.6.	0.2	2 200
		0.5	6 300
Sheltered 1	24.6.	0.7	7 100
		0.5	300
		0.5	14 900
Sheltered 2	30.6.	0.2	900
		0.5	0
		0.5	0
Sheltered 1	15.7.	0.2	1 650
		0.2	0
		0.5	2 450
		0.5	0
Open 1	16.7.	0.2	0
		0.2	0
		0.5	0
		0.5	0
Open 2	24.7.	0.2	0
		0.2	0
		0.5	0
		0.5	0
Sheltered 2	24.7.	0.2	500
		0.2	8 200
		0.5	0
		0.5	0
Open 1	11.8.	0.2	0
		0.2	0
		0.5	0
		0.5	0
Sheltered 1	11.8.	0.3	30 800
	13.8.	0.2	2 700
		0.2	5 200
		0.5	64 000
		0.5	31 500
Open 2	13.8.	0.2	950
		0.2	0
		0.2	1 900
		0,5	2 800

The clearest result of the density of *H. dissiliens* on stone surface was great variation. The sampling method gave anyway a possibility to a coarse temporal and regional comparison between sampling points sheltered 1 and open 2. *Hyalotheca* densities were greatest in August and lowest in June.

Results of study nets are given in Table 5.

Table 5. *H.dissiliens* cells in study nets.

Site	Time	H. dissiliens cells/2 ml	Fish	Water temp. °C	Wind speed (m s^{-1})
Sheltered 1	23.-24.6.	990	3	19.8	3 - 5
		1030	1		0 - 45 °
Open 2	23.-24.6.	1960	0	18.9	3 - 5
		1090	0		0 - 45 °
		1230	0		
Open 1	15.-16.7.	1085	0	18.4	0 - 3
		1100	0		90 °
		780	0		
Sheltered 1	15.-16.7.	7300	0	19.5	0 - 3
		6600	1		90 °
		5600	0		
Sheltered 1	13.-14.8.	31000	1	19.2	3 - 5
		27000	2		50 °
		62000	0		
Open 2	13.-14.8.	11000	3	19.0	3 - 5
		52000	2	19.0	50 °
		52000	1	19.0	

There were no great temporal differences between sheltered and open beach sampling points. The rise from the cell number results in June to August is quite remarkable, from 4 to 10 times.

The starting hypothesis was that *H.dissiliens* lived on stony surfaces, the main biotope in the upper part of the littoral, moved to free water when conditions were favourable and floated to fishing nets. According to the results the hypotheses was not quite correct because the number of cells found in the nets did not correlate clearly enough with the number of cells found on stony surfaces.

After this study a visual inspection in the littoral zone by a scuba-diver was done in order to find other habitats of *H.dissiliens*. It revealed that there were batches of a light green cotton-like population on muddy bottoms up to a depth of 3 m. In windy weather there were a lot of several centimeters long *H.dissiliens* filaments easily seen in the moving water mass

by the reflection of the slimy sheath in the sunshine. So there was plenty of suitable room for *Hyalotheca* to live in the littoral zone. Wave movements may remove them to free water. After these findings a more precise study of *H.dissiliens* and the littoral zone was started.

So far there is no good explanation on why *H.dissiliens* populations have started more powerful growth than ever. There is a parallel with *G. semen*, both were in earlier works mainly regarded organisms of small peat bog ponds but now they have expanded their habitat to larger lakes either humic (*Gonyostomum*) or with clear water (*Hyalotheca*). If the Swedish theory on acid precipitation as the cause of increasing *G.semen* populations is accepted it is quite acceptable also for *H.dissiliens*. An eroding process is going on in drained areas because of atmospheric acids that give to soil and ground water e.g. surplus trace metals that may be a cause of the extra growth of certain algal species. This needs a lot of additional research.

8 A C K N O W L E D G E M E N T S

I wish thank Ms. Liisa Lepistö and Mr. Pertti Manninen for co-operation and microscope analysis.

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MICROSCOPICAL EXAMINATION OF PHYTOPLANKTON SAMPLES IN NATIONAL BOARD OF WATERS AND THE ENVIRONMENT

Pirkko Kokkonen and Maija Niemelä
National Board of Waters and the Environment
PB 250, SF-00101 Helsinki, Finland

1 S A M P L I N G A N D P R E S E R V A T I O N

Phytoplankton samples are usually taken as profile samples with a tube-sampler or with a Ruttner-type water sampler. The sampling depth in inland waters is 0-2 meters. Samples are preserved with acid Lugol liquid (Willén 1962) and neutralised formalin (Throndsen 1978).

Lugol`s solution with acetic acid (Willén 1962)
Amount added 0.5-1.0 ml/200 ml sample

20 g potassiumiodide
200 ml aqua dest.
10 g resublimated iodine
20 g acetic acid

Neutralized formaldehyde solution (Throndsen 1978).
Amount added: 4 ml/200 ml sample

500 ml 40 % formaldehyde
500 ml aqua dest
100 g hexamethylenetetramine
pH 7.3-7.9
filter after one week

2 S E T T L I N G P R O C E D U R E

Water sample is sedimented in a counting chamber, which usually is 50 ml. Chambers of 5, 10, 25, or 100 ml can also be used. The samples can be diluted with the distilled water, if needed. Before the sedimentation a sample should be shaken strongly enough. The phytoplankton sample has to be kept in a room temperature before the sedimentation and in dark during the sedimentation. The sedimentation time required depends both on the volume of the chamber and the preservative used (Table 1).

Most of the blue-green algae with vacuoles and green-alga *Botryococcus* with accumalation of lipids do not sediment well. Some detergent, e.g. liquid soap can be used to facilitate the sedimentation. It has been tested, that by adding 2-3 drops of the liquid soap into the sample of 100 ml the algal bloom settlesdown in about twenty-four hours. The sedimentation of the sample proceeds faster, if the sample is mixed after a few hours the liquid soap has been added.

Table 1. Sedimentation time with different preservatives in different chamber volumes (Edler 1979).

Chamber volume (ml)	Sedimentation time (h)	
	Lugol + AA	Neutral. formaldehyde
2	3	12
10	8	24
50	24	48

The sedimentation chamber has to be wet. The bottom part of the chamber is layed on the level base, the cylinder part is slided onto the chamber. The well mixed sample is poured out to the cylinder, which is closed by sliding the round coverslip on it by pressing slightly the cylinder against the bottom part during the procedure. After the sedimentation the cylinder is slided away with the help of the coverslip, which is left on the chamber. A sample can be kept for a couple of days in a covered box together with a wet paper to decrease the evaporation.

After counting the sample all parts of the chamber have to be washed carefully under the running water using a high-quality pencil and, if needed, a liquid soap.

3 COUNTING PROCEDURE

In investigating the sample in an inverted microscope (Utermöhl 1958) light field or phase contrast illumination can be used. Usually the phytoplankton sample is studied by using the phase contrast optics to observe diatoms with slender shells, flagellas and many other constructional qualities of the algae. In examing the colour of the cells light field illumination is better.

Species can be counted from the whole area of the chamber bottom or from a certain, known part of it. In the National Board of Waters and the Environment, Finland, a part of the bottom area is counted and analyzed by using two magnifications. Nanoplankton (<20 µm) and also numerous larger algae are counted at magnification of x 800 from four stripes 1 cm in length (Fig. 1). The studied area is about 1/74 from the area of the whole chamber bottom.

At magnification of x 200 large and rare algae are counted from two diameters (Fig. 2). The area is 1/14 from the area of the chamber bottom.

The largest algae and those, which have not been

identified with other magnifications, can be studied with wide-angle oculars from the whole chamber bottom. This method is time-consuming. Normally a quick method is used, in which algae from randomly choosed 100 fields of view (1/209 of the chamber bottom) are counted or at least 500 counting units together at the magnification of x 800. The maximum error is about ± 26 %, when 60 units/species are counted (Willen 1974).

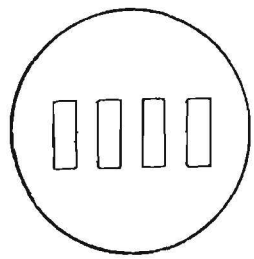

Fig. 1. Counting of algae at magnification of x 800.

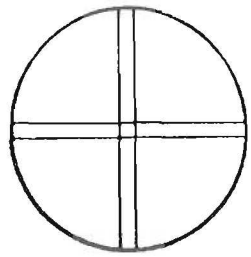

Fig. 2. Counting of algae at magnification of x 200.

It is recommended to choose the fields of view without looking at the oculars, first from the diameters and after that, if necessary, from the criss-cross stripes. The count is continued until the standard area has been examined or the standard number of units is filled (Tikkanen 1986).

The results are converted into units/100 ml by multipliers. Both the volume of water sample and the part of the counted area from the whole sample area must be considered (Tikkanen 1986).

$$\frac{a}{b} \cdot c \cdot \frac{d}{e} = \text{units/d} \qquad (1)$$

a = the area of the chamber bottom (mm^2)
b = the area of the examined fields of view or the stripes (mm^2)
c = the number of the species of the count
d = the volume of water, of which the sample is portioned (ml)
e = the volume of water sample (ml)

The multipliers to units/100 ml with different magnifications and different areas are presented in Appendix 1.

4 COUNTING OF VOLUMES AND BIOMASS

The volume of a phytoplankton species is calculated with the following method: The physical dimensions of the species are measured under the microscope. The dimensions are placed to the equation of the volume of a geometrical body that fits best to the dimensions (Appendix 2). If the shape of a species does not fit to only one equation, several equations can be used and the volumes are then summed up (Edler 1979) (Appendix 2).

In the National Board of Waters and the Environment the volumes used are based on mean values. The volumes are calculated as a cell volume, 4-6-8 cellgroups, colonies or 100 µ filaments.

By multiplying the number of the counted cells with the volume of each species the biomass of the examined sample is obtained. These values are summed up and the biomass is given e.g. as μm^3/100 ml or as wet weight mg l^{-1}, when the density of an alga is assumed to be 1.0.

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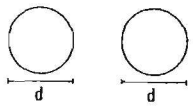
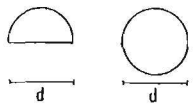
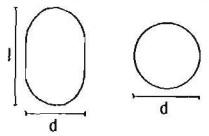
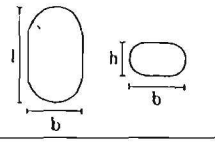
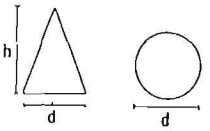
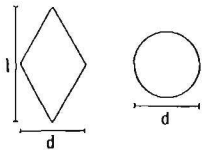
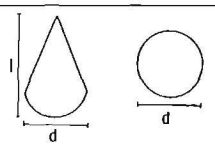
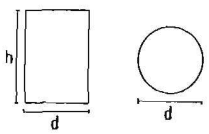
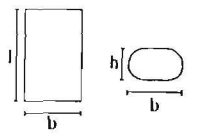
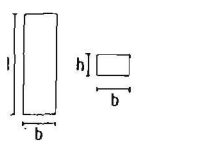
Objective x40	Multiplier/100 ml		
	The area from the whole chamber cottom	Sedimented 50 ml	Sedimented 10 ml
1 field of view (ø 180 µ)	1/20864	n. 40 000	n. 200 000
10 fields of view	1/2086	n. 4 000	n. 20 000
25 - " -	1/835	n. 1 600	n. 8 000
50 - " -	1/417	n. 800	n. 4 000
100 - " -	1/209	n. 400	n. 2 000
1 stripe (180 µ x 10000 µ)	1/295	n. 590	n. 3 000
2 stripes	1/147	n. 290	n. 1 500
3 - " -	1/98	n. 200	n. 980
4 - " -	1/74	n. 150	n. 740
5 - " -	1/59	n. 120	n. 590
Objective x10			
1 diameter (740 µ x 26000 µ)	1/28	n. 60	n. 300
2 diameters	1/14	n. 30	n. 150

Appendix 2

Geometric formulas used.

l=length, b=breadth, h=height, d=diameter

shape	cross-section	unit counting formula	examples from species and/or genera
		sphere $\frac{\pi \cdot d^3}{6}$	*Microcystis* (cell) *Chrysococcus* *Sphaerocystis* (cell) *Coelastrum* (cell)
		a half of sphere $\frac{\pi \cdot d^3}{12}$	
		rotational ellipsoid with circular cross-section $\frac{\pi \cdot l \cdot d^2}{6}$	*Cryptomonas* *Dinobryon* (cell) *Monoraphidium dybowskii* *Scenedesmus quadricauda*
		rotational ellipsoid with ellipse shaped cross-section $\frac{\pi \cdot l \cdot b \cdot h}{6}$	*Chroococcus* (cell) *Dinophysis acuminata* (?)
		cone $\frac{\pi \cdot d^2 \cdot h}{12}$	*Gonyostomum semen* *Mallomonas akrokomos*
		double cone $\frac{\pi \cdot d^2 \cdot l}{12}$	*Heterocapsa triquetra* *Chlorogonium* *Ankistrodesmus falcatus* (cell) *Scenedesmus acuminatus* *Closterium*
		cone + a half of sphere $\frac{\pi \cdot d^2}{12} \cdot \left(\frac{d}{2} + l\right)$	*Rhodomonas lacustris* *Gymnodinium helveticum* *Protoperidinium brevipes* *Mallomonas caudata*
		cylinder with circular cross-section $\frac{\pi \cdot d^2 \cdot h}{4}$	*Aphanizomenon* *Oscillatoria* *Cyclotella* *Thalassiosira* *Melosira* *Gloeotila*
		cylinder with ellipse shaped cross-section $\frac{\pi \cdot l \cdot b \cdot h}{4}$	*Chaetoceros*
		parallelpiped $l \cdot b \cdot h$	many Eupodiscales

PHYTOPLANKTON AND PRIMARY PRODUCTION IN THE LAKE RIVER SYSTEMS OF KENTI AND KONTOKKI RIVERS UNDER STRONG ANTHROPOGENIC IMPACT

Kalugin, A.I.

Karelian Research Center of Academy of Russia
Water Problem Department
185003 Petrozavodsk
Urickogo 50
Russia

1 I N T R O D U C T I O N

In connection with the construction of the Kostamus plant and the City of Kostamus the lake-river systems of Kenti and Kontokki rivers came under the influence of industrial and domestic sewage. By 1981 Lake Kostamus (the River Kenti system) was isolated by a dam and up till now it has been the waste accumulator of ore dressing production. Its mineralization increased up to 400 mg l^{-1} (potassium content being 90-110 mg l^{-1}) in 3 years. During the last two years intensive water trickling through the dam has been observed. As a result, the mineralization of the lower lakes is increasing. Since 1980 biologically treated domestic sewage has been led from the City of Kostamus.

Hydrobiological studies of phytoplankton in this region started in 1981. In this paper results of phytoplankton and primary production in the lake-river systems of Kenti and Kontikki rivers are presented.

2 M A T E R I A L A N D M E T H O D S

In 1981, 1984 and 1988-1989 the phytoplankton investigations were carried out once a year during the period when the water was at its warmest, the end of July-early August. Samples for phytoplankton studies were taken from standard depths 0, 2, 5, 10 m and from the bottom (Kiselev 1969). Fixator of our own formulas on jodine base with further fixation in 1 % formaline was used. A few samples were treated in vivo by using luminescent microscopy. Net samples were taken from the surface and from the whole water column. Primary production was determined with the O_2-method (Winberg 1960). Background material was obtained only from the River Kenti system (10 lakes) in 1981. Phytoplankton taxa were identified according to following litterature: Florin (1981), Starmach (1971), Dedusenko-Shchegoleva and Hollerbach (1962), Kosinskaya (1960), Dedusenko-Shchegoleva et al. (1959), Cleve-Euler (1950-1955), Popova (1955), Kiselev (1954), Matvienko (1954), Hollerbach et al. (1953), Korshikov (1953), Zabelina et al. (1951), Elenkin (1949) and West and West (1904-1923).

3 RESULTS

In 1981 more than 160 planktic and planktic-benthic algae (no purely benthic species) were identified. Chlorococcales, desmids, yellow-green algae, cryptophycean algae and diatoms were the most numerous groups. Compared to the River Kontokki system, the River Kenti system had more cryptophycean algae and less blue-green algae and euglenoids. The maximum biomass decreased regularly from 3.0 mg l^{-1} in Lake Okunveo to 0.5 mg l^{-1} in Lake Koivas (Table 1). Diatom genera *Synedra*, *Tabellaria*, and *Rhizosolenia* dominated in Lake Koivas. The biomass of other algae groups was 3-10 times lower. Ultrananoplankton (single algae cells of the size of 1.2-4.0 µm) stood for nearly 50 % of the total number, without a significant influence on the biomass.

Table 1. Phytoplankton biomass and photosynthesis (P) in the photic layer of the lakes of the River Kenti system during the summer period (end of July-early August).

Water body	Phytoplankton biomass mg l^{-1}			Photosynthesis mg $l^{-1}d^{-1}$ O_2	
	1981	1984	1989	1984	1989
River Kenti	1.8	0.08	0.09	-	-
Lake Okunevo	1.2-3.0	0.14-1.0	0.37	0.10	0.16
Lake Kurojarvi	0.8-2.5	0.2-0.5	-	0.30	-
Lake Poppalijarvi	0.5-1.0	0.15-0.25	0.85-0.99	0.36	0.12
Lake Jurikojarvi	0.7-1.3	-	0.20-0.40	-	-
Lake Koivas	0.15-0.50	-	0.19-0.53	-	0.35-0.45

In 1984 the phytoplankton biomass decreased remarkably compared to the year 1981 (Table 1). The blooming of *Anabaena lemmermannii* was observed. The number of diatoms was only 10 % in comparison with the same season in 1981. The variety of cryptomonads was 50 % lower. The photosynthesis in epilimnion was at its maximum, i.e. 0.2-0.3 mg l^{-1} d^{-1} O_2.

Starting in 1988, the mineralized water trickling through the dam of the tailings damp had a significant impact on the ecosystem. The dominance of the yellow-green algae biomass (*Synura*, *Mallomonas*) and the ultrananoplankton number in the three upper lakes (up to 5.5 x 10^6 cells l^{-1}) were observed. In Lake Koivas, where only the southern part was influenced by the mineralized water, yellow-green algae and diatoms have had nearly equal biomasses, and the number of ultrananoplankton was not higher than the background value (0.5-1.0 x 10^6 cells l^{-1}). The primary production of the three upper lakes remained at the level of 1984. In Lake Koivas primary production was 0.4 mg l^{-1} d^{-1} O_2 on the surface being equal in the northern and southern parts.

The phytoplankton of the River Kontokki system was studied in 1984 and 1988 (Table 2). By 1984 Lake Travyanoe and Lake Attojarvi and the lower reaches of Lake Kontokki were contaminated by domestic sewage. Production of Lake Travyanoe was 12.8 mg l^{-1} O_2 and maximum biomass 11.2 mg l^{-1} *Scenedesmus* sp. and *Cryptomonas* sp. being the predominating taxa. The maximum biomass in Lake Attojarvi was 3.2 mg l^{-1} dominant taxa being the same as in Lake Travyanoe. In the other lakes of the system the biomass was not higher than 0.6 mg l^{-1}. The dominating genera in most of these lakes were *Synura* sp., *Mallomonas* sp., *Tabellaria* sp., *Cryptomonas* sp. and *Peridinium* sp. in nearly equal quantities. The production measured in Lake Luvozero, at the mouth of the River Kontokki and in the center of the lake, was not higher than 0.3 mg l^{-1} O_2. The study of the phytoplankton of this water body system has not been finished yet.

In 1988 with the improved sewage treatment in the City of Kostamus quantitative phytoplankton indices in Lake Travyanoe decreased (Table 2). In Lake Kurkkojarvi and Lake Luvozero the florescence of the blue-green algae began. The maximum phytoplankton biomass in Lake Luvozero reached 5.6 mg l^{-1} the vertical means (0-5 m) being 0.5-1.4 mg l^{-1}. Production varied between 0.21-1.31 mg l^{-1} O_2 in Lake Luvozero and was greatest at the surface.

Table 2. Phytoplankton biomass and photosynthesis in the photic layer of the lakes of the River Kontokki system during the summer period (end of July-early August).

Water body	Phytoplankton biomass mg l^{-1}		Photosynthesis P_{max}, mg $l^{-1} \cdot d^{-1}$ O_2	
	1984	1988	1984	1988
Lake Kontokki	0.09-0.26	0.06-0.20*	-	-
Lake Travyanoe	8.60-11.2	2.90-7.70	12.8	6.64
Lake Kurkkojarvi	0.16-0.33	2.18-2.76	-	-
Lake Attojarvi	2.10-3.20	2.40-6.10	-	3.30
River Kontokki (mouth)	0.32	3.62	0.29	1.94
Lake Luvozero	0.08-0.58	0.49-5.60	0.30	1.32
River Kamennaya	0.10	0.12	0.05	0.08

* - data August, 8th, 1989

In spite of a rather weak anthropogenic impact the water quality of Lake Kontokki had apparently also changed. The biomass remained unchanged in comparison with the data of 1984 but the number of *Merismopedia* sp. increased up to $31 \cdot 10^6$ cells 1 l^{-1} (maximum-$15 \cdot 10^6$ cells dm^{-3} in 1984).

Therefore, the Kostamus ore-dressing plant and the

City of Kostamus have a significant effect on the primary link of the ecosystem of the nearby lakes. The impact of atmospheric deposition on the alkalinity of these lakes has not been revealed.

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PRIMARY PRODUCTION IN LAKE ONEGA

Timakova T.M. and Vislyanskaya I.G.
Karelian Research Center of Academy of Russia
Water Problem Department
185003 Petrozavodsk
Urickogo 50
Russia

1 INTRODUCTION

There has been no systematic studies of the phytoplankton productivity of Lake Onega. Some occasional observations had been carried out by Romanenko (1960), Sorokin and Fedorov (1969), and Trifonova and Nikolaev (1980). Umnova (1982) carried out her investigations during vegetative seasons (1978-1979), but only in the central parts of the lake, which are characterized by clearly defined oligotrophy. The separate parts of the lake have rather different kinds of productivity, especially those exposed to anthropogenic influence.

Investigations of primary phytoplankton productivity were started in 1989 in three gulfs of Lake Onega. Large Onega Gulf is in natural stage, Petrozavodsk Bay is influenced by anthropogenic load from the watershed and Kondopoga Bay by waste waters of sulphite pulp production.

These investigations included studies of the productivity of the phytoplankton and its seasonal dynamics, the determination of the intensity of the photosynthesis in the trophogenic layer and its dependence on the distribution of underwater illumination.

2 MATERIAL AND METHODS

The work was carried out by using the bottle method in two modifications: the oxygen method, developed by Winberg (1960) and the radiocarbonic method according to Sorokin (1958). The latter was based on the assimilation of labelled ^{14}C by phytoplankton (Steemann-Nielsen 1952) and it included the determination of the daily phytoplankton production in the surface sample and the relative photosynthesis rate in the water mass (Kph). To calculate the relative photosynthesis rate coefficients showing the dependence of the photosynthesis intensity on the underwater illuminance (Ki) and on the vertical distribution of active phytoplankton (Kp) were defined. Such an approach allowed not only the estimation of the production per surface area, but also the determination of the depth of the trophogenic layer (Ki curve) and the vertical distribution of active phytoplankton (Kp curve).

The parallel study of primary production with the two

methods did not give comparable results. The values of the daily photosynthesis of the radiocarbon method approximated the net production values of the oxygen method. The relationship between these values was in some cases 1:0.5. The relationship was greater (1:4) in oligotrophic areas, but it decreased to 1:2.3 when the values were calculated to production per surface area.

In spite of the abundant data on the parallel observations, there is no unanimous opinion on the difference between the results. Some authors explain it by a large variability of the assimilation coefficients. In addition, the lower values of radiocarbon method is ascribed to the reassimilation of carbonic acid breathed out by the algae and to their intravital excretion of organic matter (Fogg et al. 1965, Romanenko 1985). We assume that the latter factor was very significant in our investigations.

Taking into consideration the extensive information obtained with the radiocarbon method, we mainly used data from it, confirming them with the results of the oxygen method.

3 R E S U L T S

The depth of the photic layer in Lake Onega was determined by transparency and chromaticity. During the vegetative season transparency ranged from 2.7 to 5.5 m in Large Onega and from 1.7 to 3.9 m in the bays. Chromaticity fluctuated slightly, reaching 20° and 30-40°, respectively. The seasonal variation of the size of the photic layer in the bays was smaller than the variation between the bays.

In most cases the photic layer was three times thicker than the Secchi-depth. During the periods of the maximum algae biomass (June, August - in Kondopoga Bay; September - in Large Onega), the photic layer was only 2-2.5 times thicker than the Secchi-depth. The inhibition of photosynthesis by excessive insolation was noted only once in a very narrow surface water layer (0.25 m) in Petrozavodsk Bay. Lighting conditions for photosynthesis in the bays were optimal in a two-meter thick water layer. Deeper, particularly at the lower boundary of the photic layer, phytoplankton was subjected to light deficiency, reaching 1-28 % of the light measured at the surface. The light deficiency increased by autumn and was in an inverse relationship with the transparency (Table 1).

Table 1. Vertical light deficiency (%) in the studied bays.

Region	Light deficiency (%) at the depth (m) in July		in August	
	m	%	m	%
Large Onega	2.0	7.0	2.0	23.0
(transparency 5.5-3.9)	3.0	39.0	3.0	54.0
	17.0	86.0	12.0	91.0
Kondopoga Bay	1.5	34.0	2.0	82.5
(transparency 2.9-2.8)	3.0	81.8	4.0	97.0
	9.0	99.8	6.0	99.0
Petrozavodsk Bay	1.5	26.0	-	-
(transparency 1.7-2.5)	5.0	71.9	-	-

In addition to light conditions, production intensity is dependent on the vertical distribution of photosynthetically active phytoplankton. As was shown for Lake Onega , the number of dead cells in planktonic communities can reach nearly 50 % of the total number of phytoplankton (Petrova 1973). Therefore, the intensity of phytoplankton is not always commensurate with the density of phytoplankton. During our investigations vertical distribution of actively photosynthesizing algae in the photic layer was quite homogeneous. The curve of relative photosynthesis rate corresponded to the vertical distribution of the phytoplankton biomass.

Primary production per surface area (mg m^{-2} C) was calculated from the vertical distribution of the photosynthesis intensity. The relative photosynthesis rate (Kph), including the effect of the phytoplankton distribution and lighting conditions, changed within the range of 0.17-0.78, showing an increasing tendency in the eutrophic bays. A distinct inverse relation between this index and water transparency was observed in Large Onega.

During our investigations (excluding July) the range of the vertical means of the photosynthesis intensity was much greater in eutrophic bays than in Large Onega. The relation between the maximum and minimum values increased from 5.4 in Large Onega to 136.6 in the upper part of Kondopoga Bay, confirming the more eutrophic character of the latter (Table 2). Phytoplankton production per surface area ranged from 8.6 to 1037 mg m^{-2} d^{-1} C (Fig. 1).

Table 2. Range of the vertical means of daily photosynthesis (µg l^{-1} d^{-1} C) and relation between maximum and minimum values in the trophogenic layer during the investigation period in 1989.

Region	Daily photosynthesis µg l^{-1} d^{-1} C	Relation (max/min)
Large Onega	3.1-16.9	5.4
Petrozavodsk Bay	2.1-134.1	63.9
Kondopoga Bay (middle part)	6.5-86.5	13.3
Kondopoga Bay (upper part)	3.3-450.8	136.6

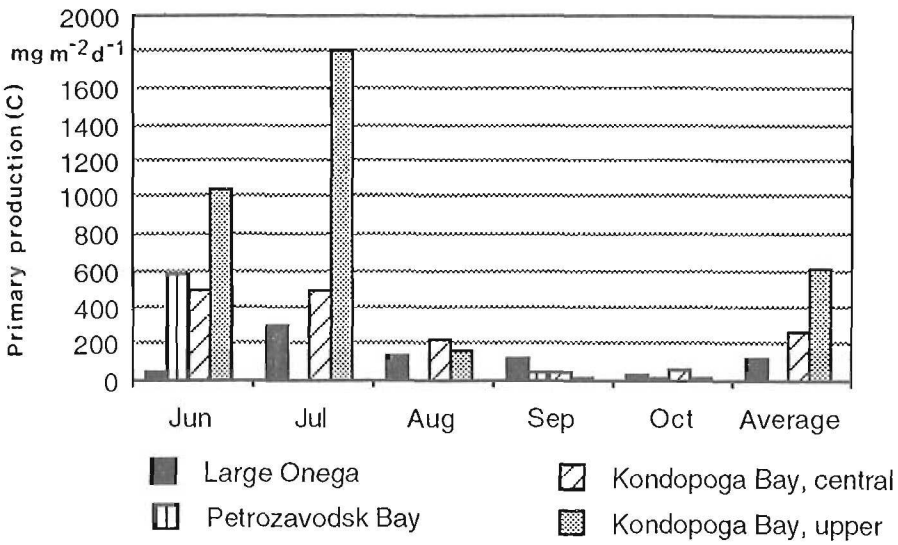

Fig. 1. Phytoplankton primary production per surface area (mg m^{-2} d^{-1} C) in the studied bays.

Although the trophogenic layer was three times narrower in the bays compared to Large Onega, phytoplankton production was higher due to eutrophy. Photosynthesis was 150-720 µg $l^{-1} \cdot d^{-1}$ C in the surface layers of the bays. The maximum production values per surface area in the layer down to 1.5 m (35-40 % of the total production per surface area) coincided with the high values of phytoplankton biomass.

In Kondopoga Bay the pulp and paper plant in its upper part is the main source for nutrient load. The distribution of the waste waters determines the regions of high productivity, which are situated mainly in the upper and the central parts of the bay. In the central part the range of mean seasonal values of mineral nitrogen was 6-100 µg l^{-1} N, and of phosphorus 14-19 µg l^{-1} P. Significant development of protococcus and blue-green algae was observed in

this area. The production of these algae was high in spite of their low biomass. In the uppermost polluted part production was 2.5 times higher than in the central part. During the investigation period the average production of the whole bay was 433 mg m^{-2} d^{-1} C. During the vegetative period (180 days) on the average 82 g m^{-2} C was produced, which corresponded to the low limit of the mesotrophic lakes.

Petrozavodsk Bay is loaded by the domestic-industrial waste waters of the City of Petrozavodsk and by the River Shuja, enriched with organic matter and nutrients. In the deepest part of the bay nitrate concentrations were 80-260 µg l^{-1} NO_3 and phosphate concentrations 2 µg l^{-1} PO_4^{-3}. The maximum production value (585 mg m^{-2} d^{-1} C) during the period of maximum algae biomass allowed us to characterize this bay as highly productive.

The Large Onega Gulf differs from the bays. Nutrient concentrations were low, which caused low primary production. Primary production was on the average 125 mg m^{-2} d^{-1} C (Fig. 1) and 26.4 g m^{-2} C during the vegetative period. In comparison with the data of Umnova (1982) the study year of 1989 was characterized by a significantly high phytoplankton biomass and was more productive than the low-productive year of 1978 and the highly productive year of 1979 (Fig. 2).

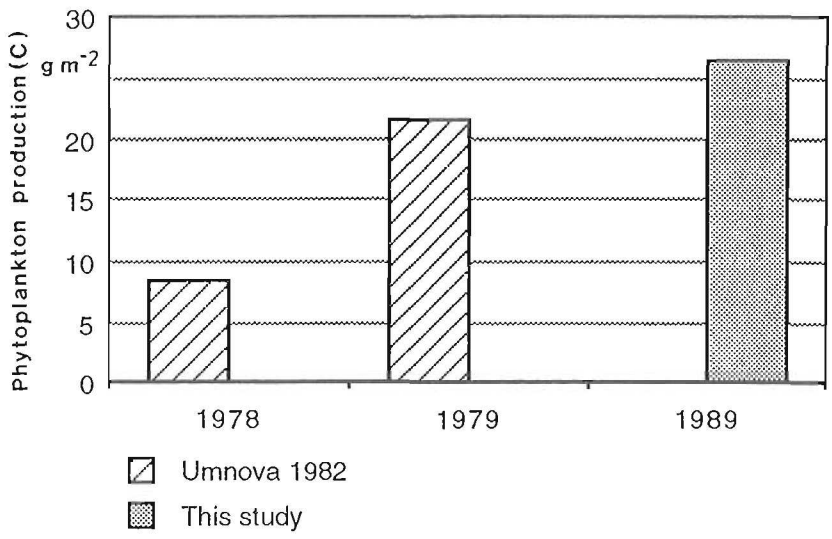

Fig. 2. Comparison of phytoplankton production during the vegetative period (g m^{-2} C) in 1978, 1979 and 1989.

The utilization of solar energy by phytoplankton fluctuated from 0.003 to 0.4 % of the total radiation measured in the surface. The smallest values (0.009-0.05 %) were observed in Large Onega and higher ones in Petrozavodsk Bay and Kondopoga Bay. The efficien-

cy of the utilization of solar radiation changed from season to season. A clear dependence between its increase and an increase in the bay's productivity was observed.

Seasonal dynamics of the primary production were determined by the thermal state of the lake and by the phytoplankton succesion. Uneven warming up of the water mass in various parts of the lake at the beginning of June promoted the formation of a thermal bar, which isolated the bays from the central part of lake. Because of this, temperature in the bays was significantly higher (8-10°) than in Large Onega (3°). The development of diatoms, dominated by *Melosira islandica* was in the beginning in Large Onega at this time. In the bays the same taxa had reached maximum biomass values. The spring maximum of diatoms was not noted, because the period of the spring turnover was very brief.

At the end of June and in the beginning of July the diatoms in Large Onega were replaced by the yellow green algae. In the bays blue-green and protococcus algae were dominant. The maximum production was measured during this period. In the following months - August, September, and October - a gradual decrease in production was observed. This process was slower in Large Onega, where rather high values, up to 119 mg m^{-2} d^{-1} C, were found even in September.

At the beginning of October an autumn peak in the primary production was observed only in Kondopoga Bay. This small peak was due to the development of the mixed population of diatomic and blue-green algae.

As a whole, the curve of the seasonal production was single-summit with the summer maximum in the low-productive part of the lake (Large Onega) and two-summit with the spring-summer and autumn maxima in the eutrophic bays (Petrozavodsk Bay and Kondopoga Bay).

The maximum production value in Large Onega occured in July and that of the biomass in June with *Melosira islandica* dominating in the plankton. Thus, seasonal production values did not always correlate with the phytoplankton biomass. During some months, these relations had the inverse tendency.

4 CONCLUSIONS

Phytoplankton development and the maximum values of biomass production characterize the year of 1989 as a highly-productive year. According to the level of primary production Large Onega Gulf is an oligotrophic water body. Central parts of Petrozavodsk Bay and Kondopoga Bay were in the lower limit of mesotrophy and upper parts were mesotrophic.

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ABIOTIC FACTORS, PLANKTON PRIMARY PRODUCTION AND ORGANIC MATTER DESTRUCTION IN THE BASINS OF KARELIA

Sabylina, A.V., Basov, M.I., Harkevitch, N.S. and Mitina, I.F.
Karelian Research Center of Academy of Russia
Water Problem Department
185003 Petrozavodsk
Urickogo 50
Russia

1 INTRODUCTION

Since the 1950's the Water Problem Department of the Karelian Scientific Center of the USSR Academy of Sciences has studied hydrochemistry of the drainage basins of large Karelian rivers Vyg, Kem, Kovda, Suma, Shuja, and Suna in connection with problems related to their economical use and protection. As a part of these studies the primary production of plankton and the destruction of organic matter have been investigated in some lakes in order to evaluate newly-formed organic matter (OM).

2 MATERIAL AND METHODS

The lakes investigated in Northern and Central Karelia were divided into three groups:

1) large, deep, oligotrophic, oligohumic with water chromaticity of 10-30°
2) average deep, oligotrophic, oligohumic with chromaticity of more than 20°
3) average deep mesotrophic, mesohumic with chromaticity up to 170° (Table 1).

In Southern Karelia mainly lakes with a surface area less than 50 km^2 were studied. The lakes were also divided into three groups:

1) deep oligotrophic, oligohumic with water chromaticity up to 16°
2) average deep, oligomesotrophic with chromaticity up to 35°
3) average deep and shallow eutrophic with chromaticity up to 112° (Table 2).

The primary production of plankton and the destruction of organic matter were determined by the Winberg (1960) method. Transparent and dark bottles were placed at every meter down to the depth of 7 meters and after 10 meters at every 5 meters down to the bottom.

In some lakes the primary production of phytoplankton was investigated with a seasonal aspect. In Lake Kamennoe and Lake Vendurskoe, for example, measurements were made every month and even more often during

the summer period. In Lake Vendurskoe daily experiments on the primary production lasted for ten days.

Table 1. Some information of the studied lakes in Northern and Central Karelia (First group OM* with 10-30° colour; second group OM** with 30-80° colour; third group OM*** with 30-170° colour).

Lakes	Year of investigation	Area of the water surface (km^2)	Average depth (m)	Water transparency (m)	Colour grad	Total ion content ($mg\ l^{-1}$)
		1st group				
Topozero (basin of the R. Kovda	1976	986	15.9	4-5	14-30	15.1-23.0
Pyaozero (- " -)	1976	943	17.8	4-5	11-30	24.9-36.3
Kovdozero (- " -)	1976	608	11.8	4-5	11-29	26.0-34.7
Segozero (basin of the R. Vyg)	1977	753	24.3	4-5	19-26	21.7-32.2
		2nd group				
Kamennoe (basin of the R. Kem')	1972-1975	101.3	7.9	5	17-35	11.5-24.1
Upper Kuito (- " -)	1982-1983	198	8.7	3-4	42-80	14.0-27.4
Middle Kuito (- " -)	- " -	257	10.4	3-4	35-46	16.2-26.3
Lower Kuito (- " -)	- " -	141	9.6	3-4	33-48	14.6-28.7
		3rd group				
Nyuk (- " -)	1979-1980	217	8.6	3-4	30-104	10.9-21.5
Kimasozero (- " -)	1975-1976	33.8	3.3	<3	40-140	12.8-37.5
Sumozero (basin of the R. Suma)	1983-1984	73.9	7.4	2-3.5	62-170	18.0-30.4

* - oligotrophic, oligohumic; ** - oligotrophic, mesohumic;
*** - mesotrophic, mesohumic;

Table 2. Some results of the studied lakes in southern Karelia (first group OM* with colour up to 30°; second group OM** with colour more than 30°; third group OM*** with 30-120° colour).

Lakes	Year of investigation	Area of the water surface (km^2)	Average depth (m)	Water transparency (m)	Colour grad	Total ion content (mg l^{-1})
			1st group			
Munozero (basin of the R. Shuja)	1968-1983	14.4	13.5	5.0	4-10	91.0-102.0
Pertozero (- " -)	1968-1983	14.3	13.0	5.0	13-16	69.0-75.0
			2nd group			
Konchezero (- " -)	1968-1983	43.6	8.8	2-4	12-15	76.1-90.2
Vendurskoe (basin of the R. Suna)	1984-1986	10	6.2	2-8	30-35	18.6-22.0
			3rd group			
Kroshnozero (basin of the R. Shuja)	1953-1987	8.9	5.7	2-3	38-112	31.2-53.4
Mikkel'skoe (- " -)	1953-1986	6.6	1.7	1,0	30-110	39.7-91.3
Svyatozero (- " -)	1953-1986	12.1	8.1	2-4	10-35	28.1-40.4

* - oligotrophic, oligohumic; ** - mesotrophic, mesohumic;
*** - eutrophic, mesohumic

3 RESULTS

3.1 ABIOTIC FACTORS

3.1.1 Mineralization (total ion concentration)

Lakes in northern and central Karelia had a low mineralization value of less 50 mg l^{-1} with small fluctuations between the lakes depending on the surface area and maximum depth (Table 1). In southern Karelia differences between the lakes studied were greater. Small deep lakes (Lake Munozero, Lake Pertozero, Lake Konchezero) had the maximum mineralization values for the studied Karelian lakes (69-102 mg l^{-1}).

3.1.2 Organic matter

The lakes of the first group in northern and central Karelia were oligohumic according to their OM content. OM was estimated from water chromaticity, permanganate (COD_{Mn}) and dichromate (COD_{Cr}) oxidabilities (editor's comment). Water chromaticity was lower than

30°, COD_{Mn} and COD_{Cr} fluctuated within the following ranges respectively: 3.6-7.3 mg l^{-1} O_2 and 7.4-17.1 mg l^{-1} O_2 . The lakes of the second group had an elevated content of allochthonous OM. Mean annual values of water chromaticity were 55°, COD_{Mn} 10 mg l^{-1} O_2 and COD_{Cr} 17 mg l^{-1} O_2. The value of organic carbon fluctuated within the range of 5.0-9.7 mg l^{-1}. All OM indices of the mesohumic lakes of the third group were 1.3 times higher than in the lakes of the second group.

Small oligo- and mesohumic lakes in southern Karelia differed slightly from those in northern and central Karelia according to their OM content . In the eutrophic lakes of southern Karelia COD_{Cr} was 8-10 mg l^{-1} O_2 in the winter and increased up to 15-20 mg l^{-1} O_2 during the stagnation period in the summer. Values of BOD_5 were 6-8 mg l^{-1} O_2 in the summer (2-3 mg l^{-1} O_2 in the winter).

3.1.3 Phosphorus, nitrogen, iron, silica, pH and oxygen

Lakes in all the three geographical zones of Karelia had quite small concentrations of phosphorus. Mean concentration of total phosphorus was ca. 25 µg l^{-1} and mineral phosphorus 2 µg l^{-1}. Concentrations of nitrate and ammonium nitrogen were also low (Tables 3 and 4). Ammonium concentration was always higher than nitrate concentration in the lakes of northern and central Karelia. In southern Karelia nitrate nitrogen prevailed. The eutrophic lakes of southern Karelia (Lake Kroshnozero, Lake Mikkelskoe, Lake Svyatozero) made an exception. Their mean concentrations of total phosphorus were two times and nitrate nitrogen two and a half times higher than in the other lakes studied (Tables 3 and 4).

Total iron content increased from the north (mean values 1-4 µg l^{-1}) to the south (mean values 300-400 µg l^{-1}). The dissolved silica concentration (mean values 1-1.5 mg l^{-1}) in the lakes studied was not a limiting factor for the development of plankton. In the eutrophic lakes of southern Karelia it came, however, down to a critical amount of 0.2-0.3 mg l^{-1} (Guseva 1975) in the surface layers during the summer stagnation period.

Water reaction of the lakes studied varied mainly from weakly acidic (6.5) to neutral (7.2) (Table 5). The studied lakes were well saturated with oxygen during the year (80-103 %). In the eutrophic lakes oxygen deficiency was observed in the summer during the stagnation period near the bottom (70-84 %) and at the same time supersaturation in the surface layers (up to 120-150 %).

Table 3. Range of total phosphorus, nitrate, and ammonium nitrogen concentrations in the studied large lakes of northern and central Karelia.

Lakes	Concentration (μg l^{-1})		
	P_{total}	$N\text{-}NO_3^-$	$N\text{-}NH_4^+$
1st group			
Topozero (basin of the R. Kovda)	6-20	6-23	60-150
Pyaozero - " -	6-20	6-46	80-140
Kovdozero - " -	6-40	6-23	80-160
Segozero (basin of the R. Vyg)	4-26	0-72	70-170
2nd group			
Kamennoe (basin of the R. Kem)	18-20	4,34	40-200
Upper Kuito - " -	9-24	10-230	40-270
Middle Kuito - " -	3-56	0-410	40-340
Lower Kuito - " -	4-27	20-330	30-230
3rd group			
Nyuk (basin of the R. Kem)	3-49	11-93	60-190
Kimasozero - " -	26-28	5-33	70-250
Sumozero (basin of the R. Suma)	9-56	0-290	20-260

Table 4. Range of total phosphorus, nitrate, and ammonium nitrogen concentrations in the studied lakes of southern Karelia.

Lakes	Concentration (μg l^{-1})		
	P(total)	$N - NO_3^-$	$N - NH_4^+$
1st group			
Munozero	14-32	0-80	20-40
Pertozero	6-23	0-100	20
2nd group			
Konchezero	17-38	0-110	20-60
Vendurskoe (1984-1985)	4-32	0-90	3-20
3rd group			
Kroshnozero (1953-1987)	30-120	0-880	20-1100
Mikkel'skoe (1953-1986)	31-118	40-600	40-190
Svyatozero (1960-1986)	33-106	0-370	20-280

Table 5. Seasonal fluctuations of pH in the studied Karelian lakes.

Lakes	pH			
	Winter	Spring	Summer	Autumn
Northern and Central Karelia				
1st group				
Topozero (basin of the R. Kovda)	6.40-6.85	6.70-6.90	6.80-7.20	6.60-6.80
Pyaozero - " -	6.60-7.20	6.90-7.10	7.00-7.40	6.90-7.10
Kovdozero - " -	6.60-7.20	6.90-7.10	7.00-7.40	6.90-7.10
Segozero (basin of the R. Vyg)	6.48-7.18	6.30-7.18	6.55-7.23	6.18-7.23
2nd group				
Kamennoue (basin of the R. Kem')	6.02-6.80	6.00-6.78	6.00-6.80	6.00-7.00
Upper Kuito - " -	6.60-6.70	6.38-7.18	6.38-6.92	6.00-6.66
Middle Kuito - " -	6.60-6.98	6.38-7.18	6.38-6.70	6.20-6.82
Lower Kuito - " -	6.40-6.60	6.70-6.70	6.38-6.82	6.62-6.98
3rd group				
Nyuk (basin of the R. Kem')	5.99-6.63	5.99-6.82	6.18-7.00	5.99-6.82
Kimasozero - " -	6.10-6.80	6.00-6.70	6.00-7.18	6.10-6.90
Sumozero (basin of the R. Suma)	6.20-6.80	6.20-6.60	6.20-6.62	6.13-6.50
Southern Karelia				
1st group				
Munozero (basin of the R. Shuja)	7.00-7.40	7.00-7.20	7.25-7.40	-
Pertozero - " -	7.01-7.38	7.28-7.70	6.87-8.80	7.11-7.50
2nd group				
Konchezero - " -	6.80-7.00	6.90-7.20	7.30-7.60	-
Vendurskoe (basin of the R. Suna)	6.34-6.40	6.77	6.59	6.37-6.77
3rd group				
Kroshnozero (basin of the R. Shuja)	6.40-7.23	7.25-7.99	6.65-10.07	7.22-7.51
Mikkel'skoe - " -	6.63-7.02	6.75-7.47	6.95-9.50	6.55-7.25
Svyatozero - " -	6.72-7.05	6.98-7.45	6.75-10.23	7.17-7.45

3.2 PRIMARY PRODUCTION AND ORGANIC MATTER DESTRUCTION

3.2.1 Northern and central Karelian lakes

3.2.1.1 Large, deep oligotrophic lakes (Group 1)

The maximum summer values of phytoplankton photosynthesis were measured in most lakes in the surface layer (0-1 m); 0.87 mg l^{-1} d^{-1} O_2 for Lake Topozero, 1.18 mg l^{-1} d^{-1} O_2 for Lake Pyaozero, and 0.60 mg l^{-1} d^{-1} O_2 for Lake Kovdozero. The mean values for the whole water column ranged from 0.01 to 0.18 mg l^{-1} d^{-1} O_2 in these lakes (Fig. 1). Primary production per square meter in the whole water column for the deep parts of the lakes (24-42 m) ranged from 0.36 to 5.67 g m^{-2} d^{-1} O_2 (Fig. 2).

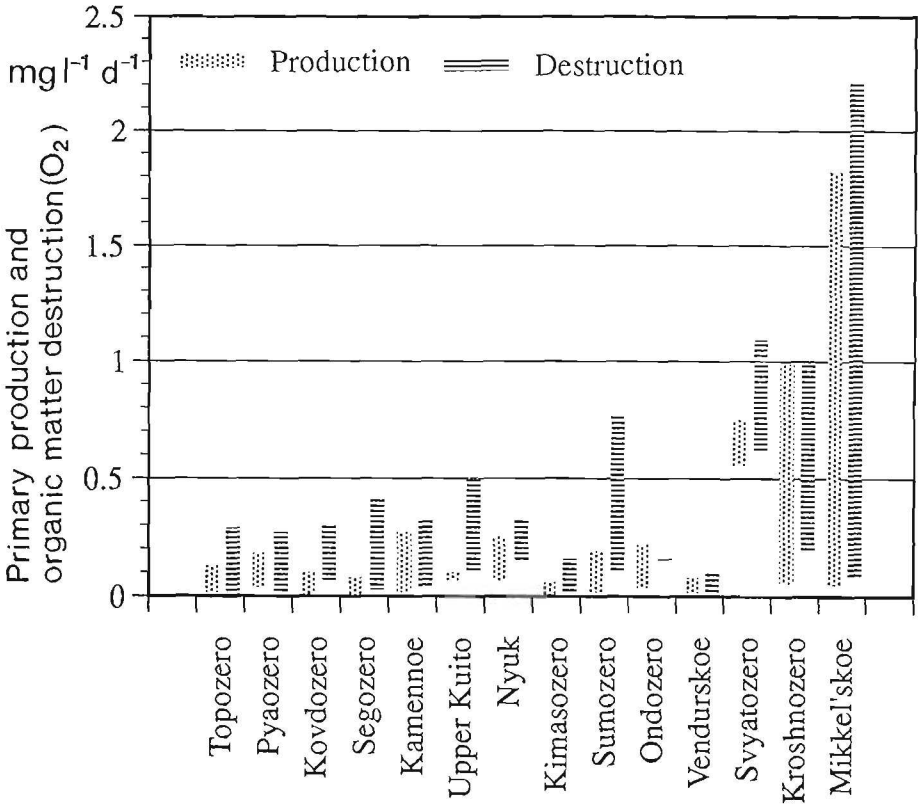

Fig. 1. Measured primary production of phytoplankton and organic matter destruction (mg l^{-1} d^{-1} O_2) in the Karelian lakes.

In Lake Topozero photosynthesis was measured down to the depth of 10 m in the summer. Water transparency was high at the same time (4-6 m) (Fig. 3). Maximum photosynthesis was observed at the depth of 5 m. Maximum concentrations of total chlorophyll and phytoplankton biomass were measured in this layer, too. It is important to note that primary production of phytoplankton in the surface water of Lake Topozero was higher in the winter (early April) than in the spring.

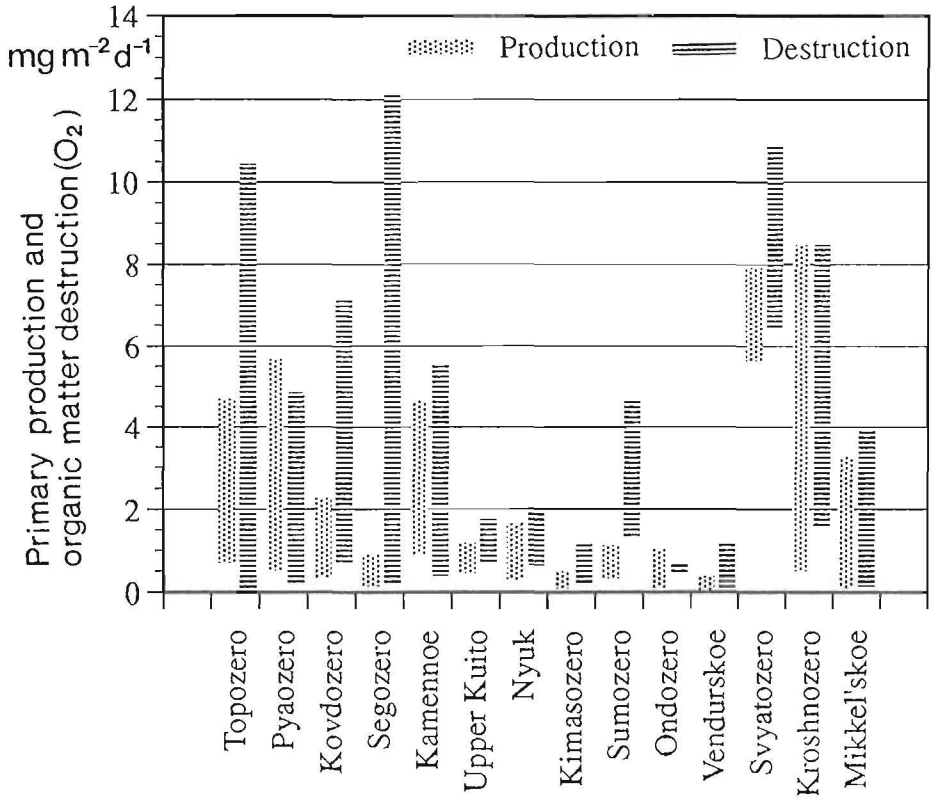

Fig. 2. Primary production and organic matter destruction per surface area (g m^{-2} d^{-1} O_2) in the Karelian lakes.

Autochtonous OM formation was very low in the deep northern lakes, only 0.1 (Lake Kovdozero, late winter) to 1.6 % (Lake Pyaozero, summer) of total OM content. OM destruction during 24 hours was two times higher than the corresponding primary production of phytoplankton.

3.2.1.2 Average deep lakes (Groups 2, 3)

Photosynthesis has been studied in detail during the spring-summer period in Lake Kamennoe. In June primary production was on the average 0.05-0.20 mg l^{-1} d^{-1} O_2 in its northern reach with the maximum of 1.05 mg l^{-1} d^{-1} O_2. In the summer primary production was rather low, mean values fluctuated from 0.04 to 0.09 mg l^{-1} d^{-1} O_2. Primary production per square meter ranged from 0.70 to 1.93 g m^{-2} d^{-1} O_2 during this period . Mean photosynthesis values were lower in the central and southern reaches than in the northern reach, being 0.02-0.03 mg l^{-1} d^{-1} O_2 during the year. Primary production per square meter was 0.24-0.28 g m^{-2} d^{-1} O_2. Autochtonous OM formation was insignificant, only 1.3 % of the total OM content.

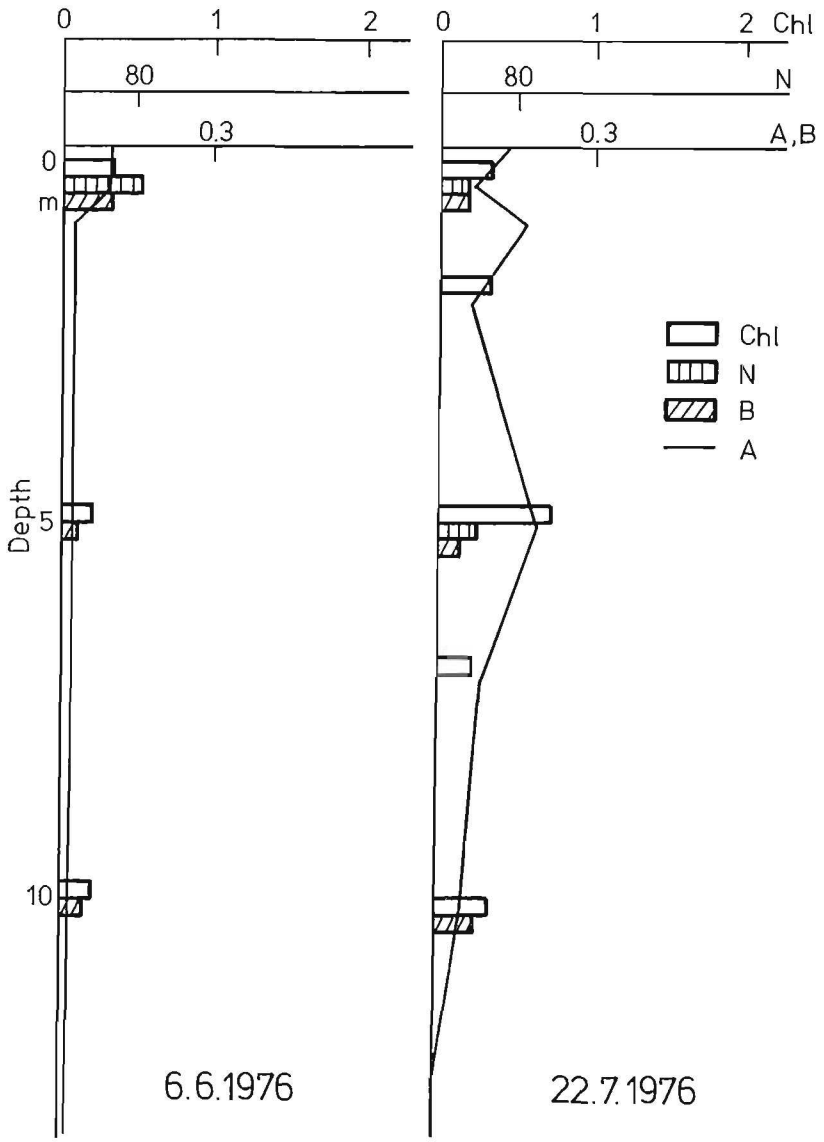

Figure 3. Intensity of the phytoplankton photosynthesis and its vertical distribution in the photic layer of Lake Topozero.

A - photosynthesis, mg l^{-1} d^{-1} O_2
N - number, thous.kl l^{-1}
B - biomass, g m^{-3}
Chl - chlorophyll (a+b+c) µg l^{-1}.

OM destruction was greater than primary production during the whole investigation period in Lake Kamennoe. Destruction increased with depth and only in the surface water layer was it sometimes lower than primary production. OM destruction was 0.41-5.52 g m^{-2} d^{-1} O_2 during the year (Fig. 2).

The primary production of phytoplankton was low in Lake Kuito, Lake Nyuk, Lake Kimasozero (drainage basin of the River Kem) and Lake Sumozero (drainage basin of the River Suma) (Fig. 1). During the spring-summer period it was 0.06-0.49 mg l^{-1} d^{-1} O_2 in Upper Kuito and 0.09-0.47 mg l^{-1} d^{-1} O_2 in the Middle and Low

Kuito. The mean summer value for primary production in the whole water column was 0.19 g m^{-2} d^{-1} O_2 for the deep parts (10-20 m) of the lakes. Photosynthesis was observed down to the depth of 5-7 m. OM destruction was 0.10-0.15 mg l^{-1} d^{-1} O_2 i.e. destruction was little higher than production.

The maximum summer destruction value (0.42 mg l^{-1} d^{-1} O_2 was analyzed in Upper Kuito at a depth of one meter It was not much greater than the photosynthesis maximum in that lake (0.32 mg l^{-1} d^{-1} O_2) (Fig. 1).

Photosynthesis was very low in mesohumic Lake Kimasozero in the winter and autumn, 0.01 mg l^{-1} d^{-1} O_2 on the average. Maximum OM destruction was observed at the surface in the winter and at a depth of 3-4 m in the autumn. Nearly 0.05 g m^{-2} d^{-1} O_2 of autochtonous OM was formed in the winter and autumn at a depth of 1 m and 0.45-1.22 g m^{-2} d^{-1} C was destructed in the winter. In the spring the mean value of photosynthesis increased up to 0.06 mg l^{-1} d^{-1} O_2 (max. 0.15 mg l^{-1} d^{-1} O_2) and in the summer it was 0.04 mg l^{-1} d^{-1} O_2 (max. 0.11 mg l^{-1} d^{-1} O_2). Primary production in the deepest sample (10 m) was 0.58-0.60 g m^{-2} d^{-1} C in the spring and 0.50 g m^{-2} d^{-1} C in the summer.

The primary production of the deep mesohumic Lake Nyuk was the same in the summer as in the spring in Lake Kimasozero i.e. 0.07 mg l^{-1} d^{-1} O_2 on the average (max. 0.14 mg l^{-1} d^{-1} O_2). In the spring higher values were, however, observed in this lake, 0.25 mg l^{-1} d^{-1} O_2 on the average (max. 1.16 mg l^{-1} d^{-1} O_2, depth of 0.5 m). The primary production at a depth of one meter in the spring was 1.65 g m^{-2} d^{-1} O_2. OM destruction in the lake was twice as high as the primary production in the spring and summer.

In Lake Sumozero photosynthesis was active in the autumn, in contrast to the other Northern Karelian lakes studied. The mean photosynthesis value was 0.19 mg l^{-1} d^{-1} O_2 (max. 0.51 mg l^{-1} d^{-1} O_2, depth of 6 m). Primary production was 0.35-1.12 g m^{-2} d^{-1} O_2 (Fig. 2).

3.2.2 Southern Karelian lakes

3.2.2.1 Oligotrophic and oligomesotrophic lakes (Group 1, 2)

In the lakes of the Konchezero group (Lake Munozero, Lake Pertozero, Lake Konchezero) photosynthesis was measured during the whole year. It is very low, however, being 0.15-0.33 mg l^{-1} d^{-1} O_2 in the summer, for example.

The summer photosynthesis intensity reached 0.97 mg l^{-1} d^{-1} O_2 in Lake Munozero, which is the uppermost lake of this system. Kuznetzov et al. (1971) have reported similar values in these lakes with radiocarbon methods. In Lake Munozero phosphate regeneration was observed in the autumn and winter. OM destruction

was two times higher than photosynthesis. Only 0.8-1.6 % of the total OM content was formed autochtonously in Konchezero lakes.

The mesotrophic mesohumic Lake Vendurskoe has been under intensive studies of primary production and OM destruction for nearly 10 years. Rather high plankton photosynthesis was observed (0.13-0.21 mg l^{-1} d^{-1} O_2) mainly in the upper water layers, but also near the bottom (11 m). In the spring the photosynthesis maximum (0.56 mg l^{-1} d^{-1} O_2) was noted at a depth of 5 m. In the summer photosynthesis was 0.05 mg l^{-1} d^{-1} O_2 for the whole water column. Destruction was always higher than production.

In daily experiments the primary production of phytoplankton (10 days) was, however, found to be rather high in June under various temperatures and solar radiation conditions. Figure 4A gives daily mean values of plankton photosynthesis and OM destruction and figure 4B gives the depth profiles for both determinations. In the surface water either photosynthesis or destruction prevails depending on the day. OM destruction prevails from three meters down to the bottom. Sometimes photosynthesis had similar values as destruction at the depth of two meters. According to the results either production or destruction prevails depending on the circumstances. On cloudy days photosynthetic processes are low and destruction exceeds them as a rule. Investigations must thus be carried out during several days.

3.2.2.2 Eutrophic lakes (Group 3)

The eutrophic lakes of southern Karelia (Lake Svyatozero, Lake Kroshnozero, Lake Mikkelskoe) differ in their primary production values from the other studied Karelian lakes not only during the vegetation period but also in the winter. For instance, the mean photosynthesis values at the end of March were 0.75 mg l^{-1} d^{-1} O_2 (max. 3.99 mg l^{-1} d^{-1} O_2, depth one meter) in Lake Svyatozero. The primary production per square meter during this period was 7.89 g m^{-2} d^{-1} O_2, i.e. higher than the OM destruction rate, which was 6.47 g m^{-2} d^{-1} O_2.

In Lake Kroshnozero plankton production increased in the summer up to 8.46 mg l^{-1} d^{-1} O_2. Figure 5 shows the seasonal OM production and destruction in Lake Kroshnozero. In 1986 production processes were lower than destruction process due to a hot summer, although both were higher than typical values of eutrophic waters (OM destruction $\approx$ 1271 g m^{-2} a^{-1} O_2 and primary production $\approx$ 515 g m^{-2} a^{-1}). In 1987, which was a cooler year, there were optimum conditions for phytoplankton development. Primary production was higher than in 1986, and in the middle of the summer it was equal to destruction.

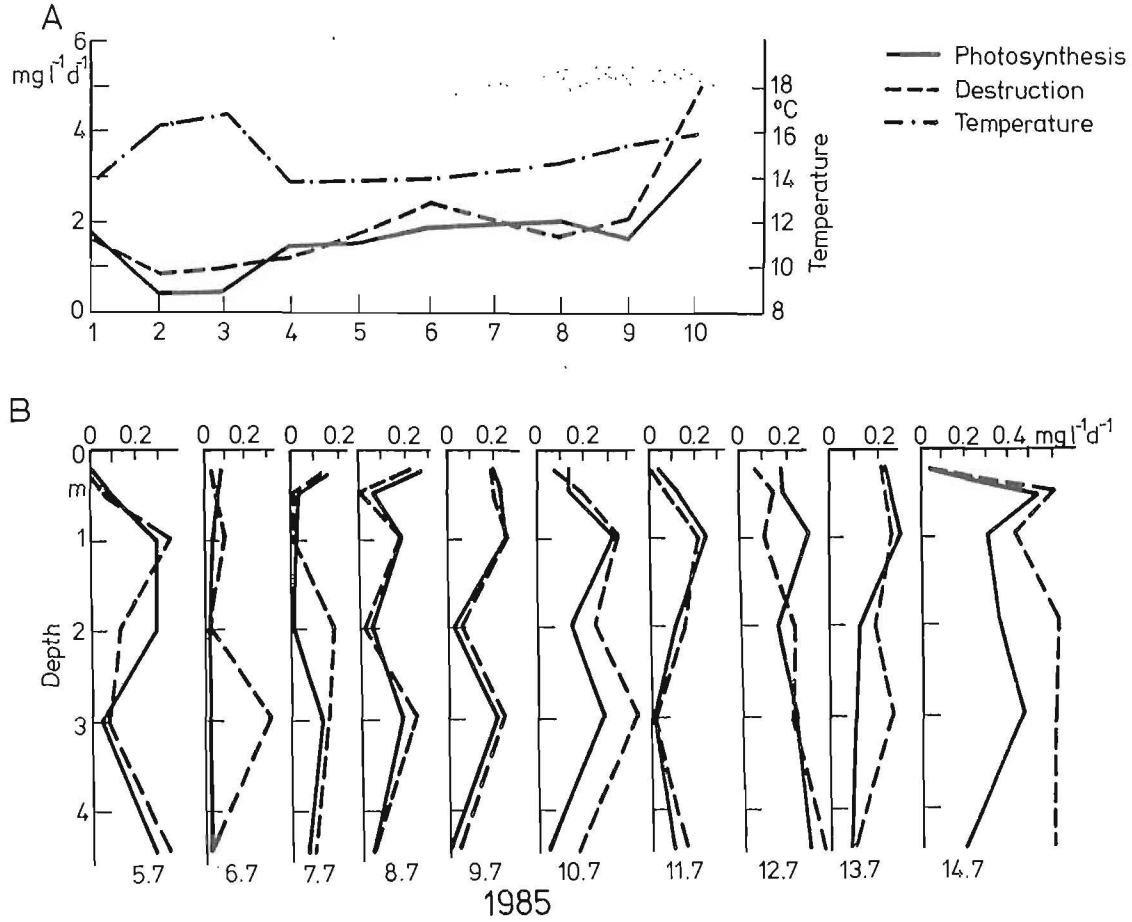

Figure 4. Change of the average (A) and absolute (B) values of phytoplankton photosynthesis and OM destruction in July 1985 in Lake Vendurskoe.

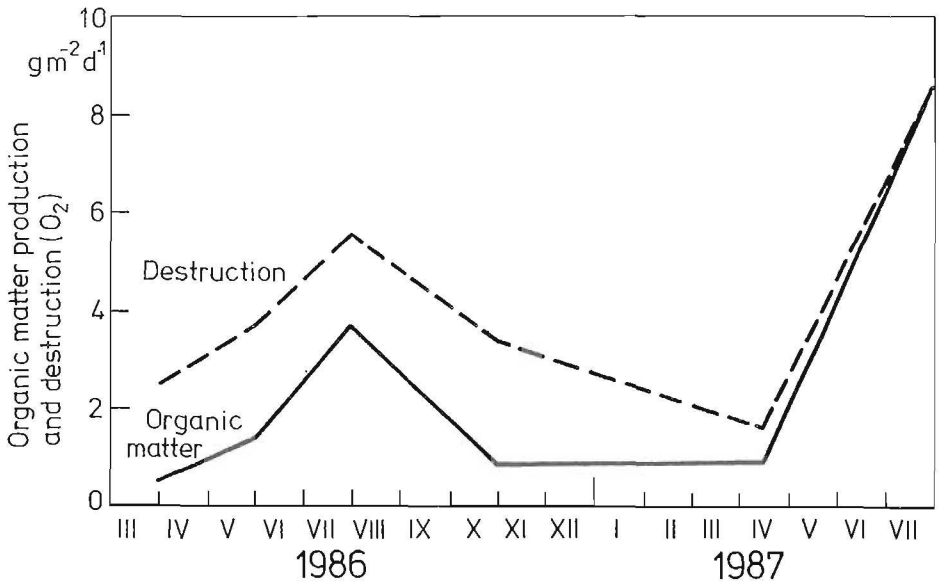

Figure 5. Organic matter production and destruction per surface area (g m^{-2} d^{-1} O_2) in Lake Kroshnozero during 1986-1987.

4 CONCLUSIONS

Low nutrient concentrations and a short period of optimum water temperature indicate low primary production of phytoplankton in Karelian lakes. The only exceptions are the eutrophic lakes of southern Karelia.

The primary production of phytoplankton was low in the lakes of northern and central Karelia. Mesotrophic, mesohumic lakes in this region had a little higher primary production than oligotrophic, oligohumic lakes. Primary production was rather high in the eutrophic lakes of Southern Karelia.

Destruction processes prevail as a rule over production during the year. This is mainly due to alloctonous OM . However, in eutrophic lakes autochtonous OM production can be equal to or somewhat higher than the OM destruction rate during some seasons.

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RESULTS OF CHLOROPHYLL a AND PRIMARY PRODUCTION IN DIFFERENT TYPES OF LAKES IN SOUTHERN AND CENTRAL KARELIA

Kovalenko, V.N

Karelian Research Center of Academy of Russia
Water Problem Department
185003 Petrozavodsk
Urickogo 50
Russia

1 I N T R O D U C T I O N

Photosynthetic pigments of seston and the rate of phytoplankton photosynthesis are often measured in studies of primary production. On the basis of the chlorophyll a concentration it is possible to evaluate phytoplankton biomass and primary production, because this pigment is responsible for the formation of organic matter in plants. Methodologically chlorophyll a is easily identified with spectrophotometric and fluorometric methods.

According to Winberg (1960) the chlorophyll a content varies within the following ranges in various water bodies: oligotrophic < 1, mesotrophic 1-10, eutrophic 10-100 mg m^{-3}. Phytoplankton chlorophyll a is used as an indicator of eutrophication and water quality, because it reflects well the nutrient loading, phosphorus and nitrogen in particular. The relation between chlorophyll a and total phosphorus has been expressed by Dillon and Rigler (1974):

$$C_{chl\ a} = 0.073\ P_{total}^{1.45} \qquad (1)$$

where

$C_{chl\ a}$ = chlorophyll a concentration (mg m^{-3})
P_{total} = mean annual concentration (mg m^{-3}) of total phosphorus.

Phytoplankton production in the basins depends naturally on lighting conditions. Water transparency (T_r) and chlorophyll a content are in a reverse relation, which can be described with the following equation (Bulion 1983):

$$C_{chl\ a} = 57.7\ T_r^{-2.17} \qquad (2)$$

where

T_r = transparency, m

Chlorophyll a shows considerable patchiness in natural waters. Because of this, remote sensing is a method of growing interest, since it allow studies with lower expenses and better areal coverage than studies made from research vessels.

2 INVESTIGATIONS IN KARELIA

2.1 RELATIONS BETWEEN CHLOROPHYLL a AND PRIMARY PRODUCTION, TOTAL PHOSPHORUS AND NITROGEN COMPOUNDS

The lakes studied were the Vendurskoe group of lakes and the lakes of the River Shuja and the River Suna drainage basins in central and southern Karelia. Field work was done during 1979-1989. The aim was to study the relation between chlorophyll a and primary production, phosphorus and nitrogen in lakes of various trophic level (oligo-, meso-, eutrophy). The method of Winberg (1960) was used for primary production and of Anon. (1960) for chlorophyll a.

Correlation coefficients between the chlorophyll a (C_{chla}) content and primary production (P) were highly significant (Pearson correlation) in many cases. In summer and early-autumn the correlation coefficient was at maximum (r=0.83) in mesotrophic lakes:

$$P = 0.294 + C_{chl\ a} \cdot 0.123 \qquad (3)$$

$r = 0.83,\ n = 94.$

In oligotrophic lakes the relation between primary production and chlorophyll a was weaker. During the winter-autumn period, when algal biomass was low, the correlation coefficient was lower.

The relation between total phosphorus (P_{total}) and chlorophyll a concentrations was at its strongest in mesotrophic and eutrophic lakes. In the first case the correlation coefficients reached the value of 0.89, in the second 0.70:

$$C_{chl\ a} = 0.324 + 24.5 \cdot P_{total} \quad r = 0.89,\ n = 146 \qquad (4)$$

$$C_{chl\ a} = 0.421 + 1.5 \cdot P_{total} \quad r = 0.70,\ n = 214 \qquad (5)$$

The correlation coefficient between chlorophyll a and nitrogen compounds depends on ammonium and nitrate concentrations, the composition of phytoplankton species, and season. The concentrations of chlorophyll a and nitrogen compounds were low, which may be the reason for the weak correlation between the two variables.

2.2 RELATIONS BETWEEN CHLOROPHYLL a AND LIGHT

Investigation of optical, chemical and biological indices of lake water have been carried out in various regions of Lake Onega since 1985. The aim of these investigations has been to study the suitability of various hydro-optic indices (albedo, transparency, chromaticity, coefficient of spectral brightness) for chlorophyll (chlorophyll a and ChlΣ) determination in the surface water layer. Coefficients of spectral

brightness have been obtained by measuring the reflected solar radiation with selenic photoelements near the water surface. Chlorophyll was determined with the spectrophotometric method (Anon. 1960).

Equations for 18 various parameters including meteorological, hydro-optical and hydrobiological indices have been obtained from the measurements performed in various regions of Lake Onega. Of the variables measured, spectral brightness explained chlorophyll a concentrations best. Chlorophyll a could also be estimated by means of temperature (t) and transparency (T_r).

For the central part of Lake Onega:

$$C_{chl\ a} = -69.4 \quad \rho_{551} + 13.2, \quad r = 0.84, \ n = 64 \qquad (6)$$

$$C_{chl\ a} = -37.5 \quad \rho_{656} + 12.75, \ r = 0.85, \ n = 64 \qquad (7)$$

where

ρ_{551} = Spectral brightness at 551 nm

ρ_{656} = Spectral brightness at 656 nm

For Lizhma Bay:

$$C_{chl\ a} = (-0.075 \cdot t - 0.54 \cdot T_r + 3.72) \pm 0.08 \qquad (8)$$

$$r = 0.85 \qquad n = 46$$

where

t = temperature (°C)
T_r = transparency (m)

For Unitzkaya Bay:

$$C_{chl\ a} = (0.021: \quad \rho_{657} + 0.104 \cdot t - 0.30) \pm 0.32 \qquad (9)$$

$$r = 0.84, \ n = 42$$

where

ρ_{657} = Spectral brightness at 657 nm

In 1989 spectral reflective characteristics (SRC) of the water surface of Lake Onega were obtained during a aerial survey. To correct the interpretation of the obtained data, samples from a research vessel were taken at the same time.

One of the SRC parameters is the colour index (I_1), which equals to the relation between the coefficients of water brightness at two narrow spectral intervals (P)

$$I_1 = \frac{\rho_{440}}{\rho_{530}} \qquad (10)$$

where

ρ_{440} = Coefficient of water brightness at 440 nm

ρ_{530} = Coefficient of water brightness at 530 nm

The wave lenghts were selected with regard to the curve of the absorption of phytoplankton chlorophyll: 440 nm maximum and 530 nm minimum absorption.

The following regression equation was obtained:

$$C_{chl\ a} = -0.575 + 65.5\ I_1 \qquad (11)$$

$r = 0.89, \quad n = 800$

3 CONCLUSIONS

This study indicates a complex relation between the chlorophyll a concentration and various water quality parameters. Chlorophyll a concentrations, and to some extent primary production, can be estimated by using the following indices: transparency, temperature, total phosphorus and coefficient of spectral brightness. The chlorophyll a determination with remote sensing methods is the most promising, because it gives a picture of horizontal chlorophyll a patchiness in a large area during a relatively short time.

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PRODUCTION OF MACROPHYTES IN THE LARGE RESERVOIRS OF KARELIA

Freindling, A.V and Klyukina E.A.
Karelian Research Center of Academy of Russia
Water Problem Department
185003 Petrozavodsk
Urickogo 50
Russia

1 I N T R O D U C T I O N

There are large lakes with both natural and regulated water levels in the territory of Karelia. They differ from each other in a number of hydrological and hydrochemical variables. The macrophyte biomass and production in these lakes as well as the degree and peculiarities of the lakes overgrowth, floristic composition and seasonal succesion depend on the natural conditions of the lakes. To find the relation between a lake's vegetation and its hydrological and hydrochemical conditions is of great theoretical and practical interest. It permits wider use of higher water plants in biomonitoring programs for surface waters.

The aim of the present study is to compare the production of macrophytes in 11 large reservoirs situated in different regions of Karelia, and to study the relation between macrophyte biomass and annual production on the lake type, degree of trophy and location.

2 T H E S T U D Y L A K E S

The study lakes were devided into two groups:

1. Lakes with natural conditions
Lake Syamozero (southern Karelia), Lake Upper (Verhneye) Kuito, Lake Nyuk, Lake Kamennoe (northern Karelia)

2. Regulated lakes
Lake Onega (southern Karelia), Lake Vygozero and Lake Ondozero (central Karelia), Lake Topozero, Lake Pyaozero, Lake Middle (Sredneye) Kuito, Lake Lower (Nizhneye) Kuito (northern Karelia).

With a few exceptions (Lake Syamozero, Kondopoga Bay of Lake Onega, Lake Vygozero) these lakes are oligotrophic with a low mineralization value.

3 RESULTS

3.1 FLORISTIC COMPOSITION

3.1.1 Lakes with natural conditions

Among the lakes of the first group, Lake Syamozero had the most dense vegetation cover. This lake has a mesotrophic littoral zone with stony-sandy and sandy sediments. The coastal line was highly cut. Macrophytes covered 3.9 % of the lake area. About 70 % of all plant communities were concentrated to the bays and inlets. Macrophyte communities were mainly found in areas close to the mouths of rivers, in gulfs, and in bays protected against rough waters, and in places where sediments are well supplied with organic substance (Klyukina 1977). The limited distribution of macrophytes throughout the lake is explained by the exposure of the stony-sandy and sandy littoral to winds and waves.

Lake Upper (Verhneye) Kuito is the largest among the examined lakes of the first group in northern Karelia. This lake is oligotrophic. The bed of the littoral zone is mainly lined with stones and boulders or with stones and sand, and it is exposed to winds and waves. The overgrowth of this lake was insignificant. Macrophytes covered small areas of shallows, and they outlined the shoreline with a narrow belt of macrophyte associations. Narrow stands of helophytes, mainly *Phragmites australis*, dominated the plant cover.

Lake Nyuk and Lake Kamennoe are oligotrophic. Their littoral zone consists mainly of stones and boulders, in some places it is rocky and exposed to the action of waves.

Higher aquatic vegetation in Lake Nyuk was poorly developed and covered only 1.3 % of the water body. On the whole, *Nuphar lutea, Potamogeton natans, Sparganium angustifolium* and *S. friesii* were dominant species (68 % of the total area of macrophyte associations). Helophytes were less common (24 %), mainly including *Phragmites australis, Equisetum fluviatilis* and *Scirpus lacustris*. Depth, type of bed, and the effect of wind and waves determined the heterogeneous extent and character of aquatic vegetation in some parts of the lake (Klyukina and Freindling 1981).

In Lake Kamennoe macrophytes covered only 1.2 % of the water surface area because of the unfavourable growth conditions. Helophytes dominated (71 %), *Phragmites australis* and *Equisetum fluviatile* covering 41 and 15 % of the total area of aquatic vegetation, respectively (Klyukina 1979, Klyukina and Freindling 1981).

3.1.2 Regulated lakes

Lake Onega which was converted into a reservoir in 1953 is the largest among the water bodies of the second group (regulated lakes). It is oligotrophic, and some of its bays and inlets have mesotrophic features (e.g. Kondopoga Bay). Stony and stony-sandy bottoms with admixtures of gravel prevail in the littoral zone. The shores are generally exposed to the intensive action of wind and waves. Macrophytes covered 0.2 % of the lake's surface. The estimate was higher in the shallows and isolated inlets, 11.3 % in Svyatuha and Keftenguba, and 1.5 % in Unitskaya. The communities of *Phragmites australis* predominated the vegetation cover in all parts of Lake Onega. *Scirpus lacustris* and *Equisetum palustre* occupied an insignificant area. Nympheids were widely distributed, especially *Nuphar lutea* and *Polygonum amphibium*. The assemblages of submerged plants, mainly *Potamogeton perfoliatus* were poorly developed (Raspopov 1975).

Mesotrophic Lake Vygozero was converted into a reservoir in 1932 and it is the oldest one in Karelia. The bottom of the littoral zone is lined with stony-boulder and stony-sandy sediments. The shoreline is exposed to wind and waves. Macrophytes covered 0.4 % of the reservoir area. A significant part of the shallows was occupied by flooded wood and mats of plants. Sometimes separate stands of water plants were encountered there, but they did not form any considerable associations. Aquatic vegetation was most abundant in the shallows of the inlets and bays in the southern and northern parts of the reservoir. The aquatic vegetation is influenced by the intermittent changes in the water level and the annual deaquation of the littoral during the regulation of the reservoir. The macrophyte succession of this water body has not yet been completed, despite the fact that the process has continued for over 40 years (Klyukina 1978). This indicates the long-term process of succession of a reservoir in northern conditions.

Lake Ondozero was converted into Ondo-Vygozero Reservoir in 1946-1956. At present it has mesotrophic features. Its littoral zone consists of sandy, sandy-stony and silty bottoms. Aquatic plants covered 1.1 % of the water surface of the lake. Macrophytes were most abundant in the northern shallow part characterized by sandy-silty and sandy bottoms in the littoral zone and a deforested shore-line. The poorest aquatic vegetation was found in the middle part, where there is a shallow zone lined with stony-boulder bottom and exposed to winds and waves. The communities of *Nuphar lutea, Potamogeton natans, P. perfoliatus* and *Polygonum amphibium* were the main components of the aquatic vegetation cover, making up 76 % of the total area occupied by macrophytes.

Lake Topozero and Lake Pyaozero, which are the largest among the water bodies of Northern Karelia, were

converted into the Topo-Pyaozero reservoir in 1958-1960. It belongs to the oligotrophic type. Its littoral zone is poorly developed and lined with stony-gravel and sandy sediments. The shore-line is highly exposed to the dynamic influence of waves. During the construction of the reservoir the water level was lowered in Lake Topozero and elevated in Lake Pyaozero. The conditions for the growth of macrophytes have changed in a newly-formed littoral zone. Macrophytes occupied 0.5 % of the area of Lake Topozero. In general, they were found in shallows, near the mouths of rivers and in the areas protected against water disturbance. In the newly formed littoral zone of Lake Pyaozero flooded and underflooded scrubby and woody vegetation prevailed and therefore the conditions for the development of macrophytes were extremely unfavorable (Klyukina and Freindling 1979).

Lake Middle (Sredneye) Kuito and Lake Lower (Nizhneye) Kuito were converted into the Jushkozero Reservoir in 1975-1980. It belongs to the oligotrophic type. Its littoral zone is poorly developed and made up of stony-boulder and sandy-boulder sediments. The shore-line is highly exposed to the dynamic effect of waves. Flooded woody and scrubby vegetation was found in its shallow zone. This kind of vegetation prevents macrophyte growth. There were some individual water plants that formed "islets" or "spoots". The succession of the vegetation cover was only just beginning.

3.2 MACROPHYTE BIOMASS

The estimates of biomass of macrophytes in the lakes varied within a wide range, due to differences in natural conditions.

3.2.1 Lakes with natural conditions

Among the non-regulated lakes, the highest biomass values were recorded in Lake Syamozero (Table 1). The highest total production values were not recorded in this lake, however (Fig. 1). Helophytes dominated the macrophyte biomass. *Phragmites australis* alone made up 86 % of the annual production of macrophytes (Klyukina 1977). It was widely distributed in the lake.

Macrophyte biomass in Lake Verhneye Kuito was very low, except for *Phragmites australis* and *Polygonum amphibium*. Lake Nyuk cale and Lake Kamennoe had similar features (Table 1).

In Lake Kamennoe, helophytes were the main producers of biomass (66 % of annual estimate), *Phragmites australis* contributing 55 %. In Lake Nyuk, floating leaved macrophytes were very significant, mainly *Nuphar lutea* (30 % of biomass), and to a less extent *Potamogeton natans* and *Sparganium anguistifolia* and *S. friesii*. *Phragmites australis* was the main produ-

cer among helophytes (32 %) (Klyukina and Freindling 1981).

The estimates of macrophyte production per surface area in Lake Kamennoe and Lake Nyuk were on the same level, those per vegetation congestion area were higher in Lake Kamennoe because of the stands of *Phragmites australis* (Fig. 1).

Table 1. The biomass of aquatic plants (g m^{-2}, air dry substance).

Reservoir	Phragmites australis (Cav, Trin ex Steud	Scirpus lacustris L.	Nuphar lutea (L.) Sm.	Potamogeton natans L.	Polygonum amphibium L.	Potamogeton perfoliatus L.
Syamozero	260	101	66	72	75	160
Upper Kuito	114	33	29	25	30	22
Nyuk	56	50	35	30	18	41
Kamennoe	77	58	64	90	-	-
Lake Onega*	220	187	150	142	77	32
Kondopoga Bay of Onega Lake	189	273	83	86	156	75
Vygozero	175	-	60	55	-	-
Ondozero	94	86	45	34	34	326
Topozero	119	104	43	86	-	75
Middle Kuito	-	-	12	8	7	24
Lower Kuito	97	-	22	6	18	20

*Data of Raspopov (1975), absolutely air dry substance

3.2.2 Regulated lakes

Among the Karelian reservoirs studied, the most productive macrophyte communities were noted in Lake Onega. The phytocenosis of *Phragmites australis* was the main producer of biomass. The average estimate of the lake's macrophyte biomass was 220 g m^{-2} and it ranged from 68 to 712 g m^{-2} absolutely dry substance (Raspopov 1975). The productivity of *Phragmites australis* in Kondopoga Bay was lower than the average value for the whole Lake Onega (Table 1) due to anthropogenic pressure.

The littoral zone of the bays was poorly developed, with rocky and stony substrates dominating. The narrow phytocenoses of common reed grew in strata between islands and in hollows by the shore.

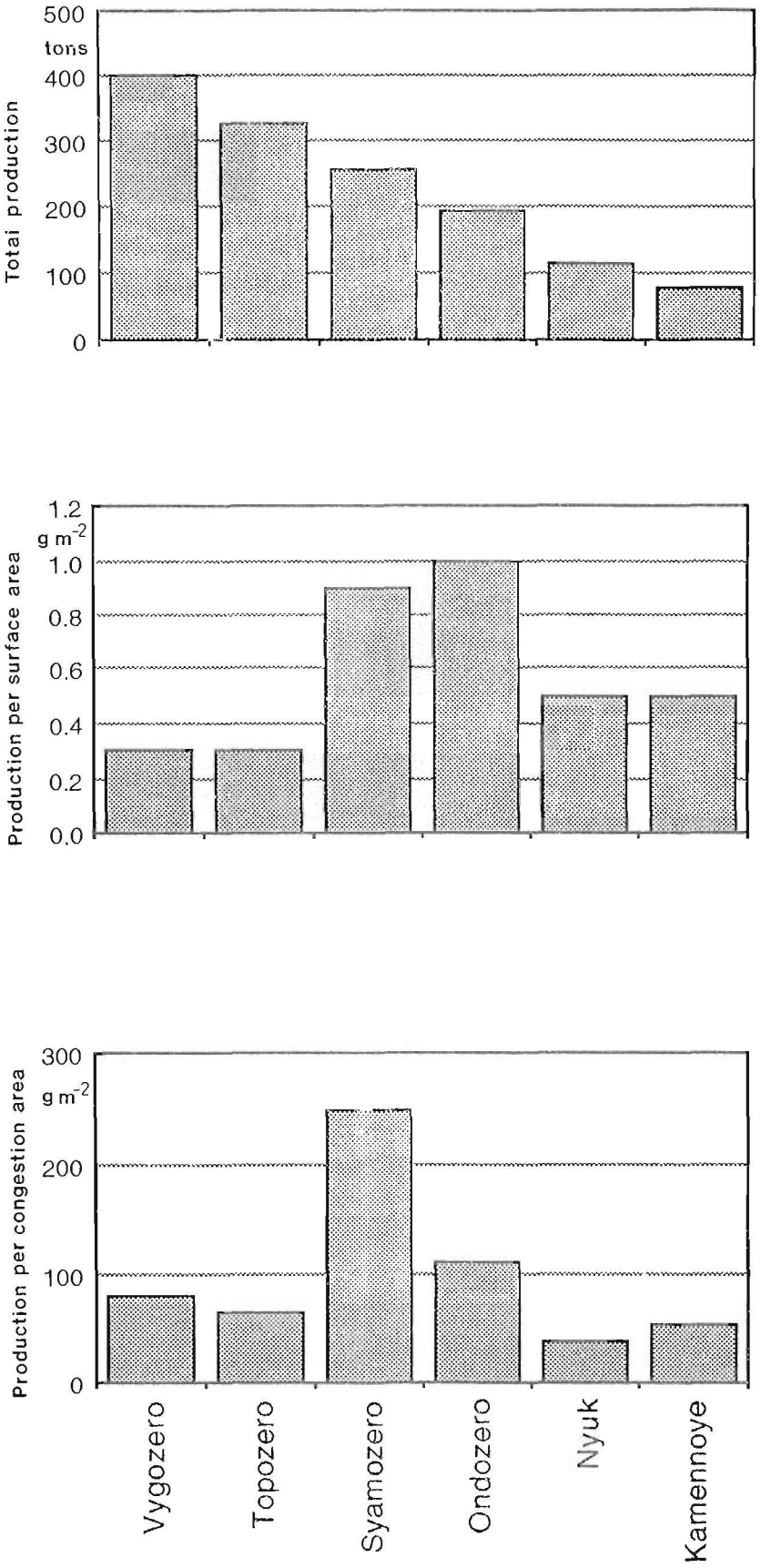

Fig. 1. Annual production of macrophytes (air dry substance).

In places sheltered from the waves near Kizhi island, some stands of common reed were found to have biomass close to the lake's average estimate, and in some places even higher. For example, the biomass in Shunga Inlet (Povenets Bay) was 3-3.5 times above the average. Unlike the other parts of the lake, the water in these protected places was richer in nutrients and had increased mineralization (Raspopov 1973).

In Lake Vygozero helophytes played an important role in plant biomass formation (61 %), the productivity of plants with floating leaves being much lower. The community of *Phragmites australis* and *Equisetum fluviatile* each contributed 30 % of biomass, although *Phragmites australis* occupied a two times smaller area. The biomass of *Nuphar lutea* was 1.5 times less than that of *Equisetum fluviatile*, although they covered the same area. Occupying the same area as common reed *Potamogeton natans* and *P. perfoliatus*, and *Sparganium friesii* and *S. angustifolium* had less biomass (only 9.7 % and 3 % of total value).

The main producers of biomass in Lake Ondozero were neustons and hydatophytes giving 78 % of the annual production, *Potamogeton perfoliatus* contributing 50 % (terminology according to Raspopov (1977)). Its biomass was as high as 326 g m^{-2} air dry substance. This value is rather high for the hydatophytes of the Karelian lakes. *Potamogeton perfoliatus* covered 12.6 % of the total area covered by macrophytes. Helophytes had a limited distribution in the lake.

The intermediate value of total production of macrophytes in Lake Ondozero was due to low productivity of *Potamogeton perfoliatus*. Calculation of the production per surface area or per the plant association area gave the highest values among the lakes studied (Fig. 1).

The high productivity of phytocenoses in Lake Vygozero and Lake Ondozero is due to the favorable conditions: a better supply of sediment and water with organic substance and nutrients, a longer period after the beginning of regulation (Lake Vygozero) compared to the northern reservoirs, shallowness and short turnover time of nutrients in the shallow zones (Lake Ondozero).

The productivity of the phytocenoses in northern water-bodies - Lake Topozero, Lake Middle (Sredneye) Kuito and Lake Lower (Nizhneye) Kuito - was low (Table 1). Due to the short period since the formation of the lakes and the unfavorable conditions of macrophyte growth, there were no complete plant associations.

Helophytes were the main producers (73 % of the total biomass) in Lake Topozero making up 40 % of the coverage of plant associations. The main producer, common reed, covered 20 % of the total area covered by macrophytes, making up 20 % of the annual production.

The assemblages of *Scirpus lacustris* and *Nuphar lutea* produced 20 and 13 % of the annual production, respectively. Production of submerged plants was insignificant.

4 CONCLUSIONS

Large regulated and non-regulated water bodies of Karelia differ in terms of macrophyte production. Among the lakes with no regulation Lake Syamozero had the most developed vegetation cover. Lake Syamozero is a mesotrophic water body situated in the south of Karelia. The vegetation assemblages of the northern lakes - Lake Upper (Verhneye) Kuito, Lake Nyuk, and Lake Kamennoe - were less productive, the estimates of plant biomass and production being lower.

The aquatic vegetation in regulated reservoirs was less abundant. In regulated lakes, or in their separate parts with higher trophic levels, the aquatic vegetation was denser with greater biomass. In the water bodies studied, the most productive macrophyte communities were found in the parts of Lake Onega (southern Karelia), which have been subjected to the process of eutrophication, and in mesotrophic Lake Vygozero (central Karelia).

In northern oligotrophic reservoirs, phytocenoses were poor and biomass was low. The aquatic vegetation of these reservoirs were just at the initial stage of succession.

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MACROPHYTE MONITORING PROGRAM IN FINLAND

Lauri Heitto
National Board of Waters and the Environment
PB 250, SF-00101 Helsinki, Finland

1 B A C K R O U N D

Intensive biological monitoring of Finnish inland waters was started in 1989. The aim of the programme is to have a network of study areas (lakes or parts of lakes) covering whole Finland where to study and to monitor different biological groups for detecting changes in the lake environment. Extensive phytoplankton studies have been under way in some lakes since 1960's and also periphyton studies were started before 1989. Samples for benthic invertebrates and zooplankton were taken in the first year of the monitoring program and macrophyte studies started in 1990.

2 L A K E S

Finland is divided into 13 water and environment districts and there are in principle two study areas per district included in the program, one oligotrophic and one eutrophic, a total of 24 inland waters. The study areas are quite large and parts of the largest lakes in Finland belong to the program (Lake Saimaa, Lake Päijänne, Lake Inari).

3 M A C R O P H Y T E M O N I T O R I N G P R O G R A M

Plannig a macrophyte monitoring program is quite a difficult task and in the beginning next questions have to be answered:

1) Why to monitor macrophytes?

2) What questions are being asked?

3) What sampling design is best for combining the questions asked and resources given?

3.1 WHY TO MONITOR MACROPHYTES?

3.1.1 T h e r o l e o f m a c r o p h y t e s i n a l a k e e c o s y s t e m

Macrophytes influence many lake ecosystems in a variety of ways (Raschke and Rusanowski 1984):

1) They convert light energy and mineral nutrients to organic matter

2) They are an important consumer food source through grazing and detrital food webs
3) They serve as a substrate for a diverse assemblage of attached microscopic and macroscopic plants and animals
4) They serve as a spawning substrate for aquatic vertebrates and invertebrates
5) They serve as a cover and nursery area for both aquatic vertabrates and invertebrates
6) They have the ability to trap and recycle nutrients
7) They have the ability to build and stabilize substrate
8) They serve as a source of oxygen

Thus changes in macrophyte communities affect many other biological communities.

3.1.2 Potential for detecting environmental changes

Macrophytes form species-poor communities compared to zoo- and phytoplankton and zoobethos communities. This complicates the use of macrophytes for water quality assessment (Wiegleb 1981). Many macrophytes live in close connection with sediment and are thus affected not only by water quality but also by sediment quality, which also reduces their value for water quality indication. Lemnids, ceratophyllids, many bryids and elodeids are suitable for early warning indication of water quality, however, because they react quite quickly to changes in trophic status, for example (Toivonen 1984). Perennial, large helophytes, for example, are best suited for long-term monitoring purposes, e.g. in connection with water quality restoration, for the assessment of the influence of hydroelectric power and water level regulation projects, especially in shallow, eutrophicated water bodies, as they usually reflect changes in the environment within 5-20 years (Niemi 1990). In larger lakes macrophytes reflect changes in the littoral zone.

3.2 QUESTIONS TO BE ASKED

Macrophytes can in principle be used as bioindicators in three ways (Melzer 1985):

1) in plant tests carried out under controlled laboratory conditions,
2) by using the chemical contents of certain species as bioindicators of heavy metal of other toxic loads, and
3) by studying changes in flora or vegetation

Macrophyte studies of intensive biological monitoring of inland waters will concentrate on the changes in aquatic vegetation, because the program is based on field studies and heavy metals are being monitored by the water authorities in other programs. The first question to be asked is then:

1) Has there been any change in vegetation in a particular water body?

If changes have been notised the next question will be:

2) Are changes due to large natural variability typical in aquatic vegetation or has there been environmental changes?

If changes are due to some environmental changes the last question will be.

3) What are the reasons for changes?

These questions are very complicated. Question number one has many methodological difficulties which will be studied during the first two years in a preliminary study. To be able to answer the last two questions more knowledge is needed on the ecology of aquatic macrophytes. This can be achieved by long-time monitoring program and by macrophyte survey of different kind of lakes (reference lakes are needed for impact studies). In situ -field studies and laboratory studies are often neccesary for at least the question number three. Because of the quite large number of lakes included, this program serves both as a macrophyte survey and as a monitoring program. These questions can thus be within the scope of this study in the future.

3.3 SAMPLE DESIGN FOR THE PRELIMINARY STUDY

3.3.1 Objective

How to document aquatic vegetation so that chances can be detected?

3.3.2 Resources

Before designing the sampling program the resources given must to be taken into account. During the two years the macrophyte study has one half time scientist (half an year per study year). Research equipment and many facilities (e.g. limited number of laboratory analysis, car, boat, accomodation) are provided by the water and environment administration. Resources for new equipment and air photos are limited to 5 000-10 000 mk per year.

3.3.3 Selection of lakes

Two lakes, one oligotrophic and one eutrophic, were selected of the 24 lakes for the preliminary study. These two lakes were selected with a help of a principal component analysis in order to represent 'average' lakes. Data of different characteristics of the lakes (length of ice cover time, ranges of water

level regulation, lake water colour and total phosphorus concentration) were used and the final desicion was made accordig to travelling costs.

3.3.4 Selection of methods

What parameter of plant vegetation is sensitive enough to give comparable results for detecting changes and is suitable for monitoring purposes? Is it in the level of an individual plant, plant population, community or whole lake ecosystem (Farmer and Adams 1989)? For monitoring purposes community level studies are quite usual and they will be used in this preliminary study. Methods used by water authorities have been summarized by Nybom (this volume). Niemi (1990) reviewed methods for monitoring purposes and his paper serves as a base for the following discussion.

3.3.4.1 Aerial photography

Aerial photography is the best way to get information of the zonation of different plant communities. Also satellite images has to be taken into account, because the digital nature of the recordings allows computer processing (Golterman et al. 1987). At the moment their use is limited because of their low resolution. The spatial resolution is about 30 m x 30 m in Landsat images and 10 m x 10 m in Spot images. The price is also quite high at the moment (about 9000 Fmk/image). Video has better resolution and it will be tested during the preliminary study. All these technics need a visit to the lake, however, because the information got is not detailed enough (submerged plants are impossible to identify to species level, for example).

3.3.4.2 Location of sampling sites

Sites for sampling may be selected by three methods (Gertz 1984):
1) random selection
2) regular or systematic selection
3) preferential selection

Random selection allows accurate species abundance or parameter estimates and subsequent hypothesis testing. In regular or systematic selection results are not unbiased estimators, which means that they can give accurate results of population size and density, but the results cannot properly be used for hypothesis testing. In prefential selection the site selection may introduce sizeable sampling errors and the results are for descriptive purposes only (Gertz 1984).

Random selection has one disadvantage for monitoring purposes. To meet acceptable variance limits the number of sampling sites is very high. Stratified random design is one commonly used method to reduce

the number of samples (Dennis 1984). In this design the lake is subdivided into subpopulations (strata) according to habitat factors and sampling sites are selected randomly from these subpopulations. Observations should be most alike within a strata and most different between strata. A stratified random system is nonbiased as random system, and it has thorough coverage of the study area like regular sampling system (Nichols 1984).

In this study the shoreline will be divided into four strata according to their depth profile and openness to winds and waves. The method will be analyzed after the first study year.

3.3.4.3 Number of sampling sites

This is a very important and difficult question: What is the minimum number of sites to adequately describe the vegetation. Macrophytes especially have great vegetational variability (Nichols 1984).

In this preliminary study the number of sampling sites will be calculated using the Jensen (1977) method, which takes into account the length of shoreline and lake area. The results will be estimated with the help of statistical analysis and aerial photography.

3.3.4.4 Sampling method

The possible variations of macrophyte samplig designs are many, but according to Gertz (1984) they all fall into two general categories, plot or quadrat methods and plotless methods. For purely descriptive result plot or plotless design may be used, but in impact studies with stastistical hypothesis testing a plotless technique is better (Gertz 1984).

Line transect method (plotless method) is commonly used by the water administratation (Nybom, this volume). The line is most commonly perpendicular to shore. This makes the results quite heterogeneous, which means some problems for data handling. Quadrat methods have not this problem, but the marking of several permanent plots for a long-time monitoring program is difficult. Line transects will be used in the preliminary study.

How detailed information is needed for adequate documentation of vegetation? There is no consensus of ecologists which indicators should be used to describe the importance of a plant in a community (Nichols 1984).

Presence-absence data is the quickest to get and it gives possibilities to calculate frequency values, but is of quite coarse quality. Adding cover values to species list gives a lot more information. Direct percentage estimates are preferred to coverage classes

among Finnish botanist (Oksanen 1976). Direct percentage are time consuming to get and if there are several researches cover classes should be used because of objectivity (Oksanen 1976). Because of many cover classes used, some theoretical study of the sensitivity of different type of cover classes to environmental changes should be done during the preliminary study (Niemi 1990).

More detailed studies include plant density, biomass and productivity. Taking into account the resources given the measurements done during the preliminary study are species composition and cover.

Concentrating studies to permanent sampling sites enables the phytosociological approach to the description and classification of aquatic macrophyte vegetation. In this way the results would be more comparable to studies made in central Europe, for example. According to Mäkirinta (1978) the fytocoenosis of Finnish aquatic vegetation have not been mainly described, which means that this approach would need more resources than available in the preliminary study. This question must be debated in the future.

3.3.4.5 Data handling

The power of different statistical analysis to detect changes in the vegetation will be evaluated in the preliminary study. Methods to describe the data will also be tested. Water administration is developing a data bank for biological studies. One part of the preliminary study is to plan the macrophyte part in this register.

4 S U M M A R Y

Macrophyte monitoring program in Finland will start with a two year preliminary study. During the two years methods to describe aquatic vegetation in a manner detailed enough to detect chances in the vegetation will be studied. Two lakes out of the 24 lakes belonging to the intensive biological monitoring program of Finnish inland waters are included in the preliminary study, one oligotrophic and one eutrophic.

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LAKE RESTORATION AND MACROPHYTES

Pirjo Hiltunen
The Water and Environment District of Mikkeli
PB 77, SF-50101 Mikkeli, Finland

1 NEED OF LAKE RESTORATION

The need of lake restoration has emerged, because lakes have been changing, and on the other hand, people want to use lakes more than before (Lakso and Alasaarela 1990). Most of these lakes are shallow where the water level has been lowered. Eutrophication and overgrowth by macrophytes have worsened the situation in the lakes. But with different restoration techniques it is possible to improve the lakes which are in a poor condition. These methods include e.g. the cutting of the macrophyte vegetation, the raising of the water level, dredging and aeration (Nybom et al. 1990).

The authorities get information of the needs and expectations of the people in the form of various petitions and initiatives, which are sent by e.g. communes, fishing corporations and private persons. The needs of lake restoration are most common in densely populated areas.

2 BASIC INVESTIGATION

The changes in lakes may be various and it is not always easy to find out why the lake has certain kind of problems. And it is most difficult to influence the condition of the water body.

In order to proceed in lake restoration, the present condition of the lake must be known, before proper planning can be designed. The matter can be cleared up only with different kind of investigations and reports (Björk 1985).

The planning of lake restoration projects must start in good time with biological investigations, so that technical and ecological information will be available, when a planner starts his project. In the first phase it should be made clear, if there are any factors which prevent the total venture or part of the alternatives (Fig. 1).

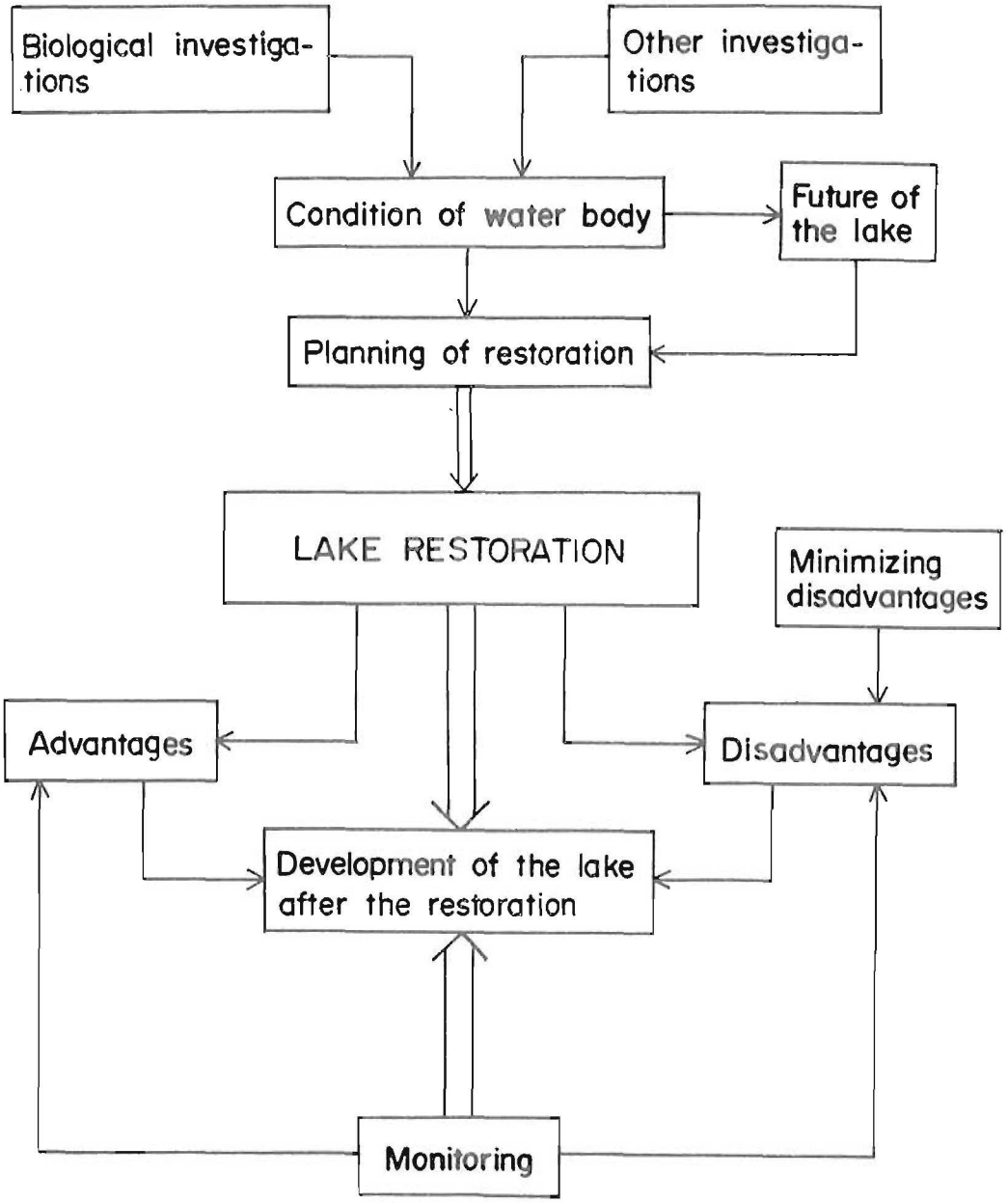

Figure 1. Planning of lake restoration.

3 IMPORTANCE OF THE MACROPHYTE INVESTIGATION IN THE PLANNING OF LAKE RESTORATION

The importance of the biological investigation in the planning of lake restoration will come up especially when the project has a remarkable value as a protected area. These kinds of areas are e.g. the lakes which belong to the protection program of the waterflow wetlands (Komiteamietintö 1981). Also in other kinds of repairing areas the starting point of the planning must be a sufficient ecological knowledge of the lake

ecology. The most important biological investigations deal with the aquatic vegetation and its succession. That is why water areas must be mapped by the aid of aerial photographs (Toivonen and Nybom 1989).

Dense aquatic mosses have caused special problems to the restoration in shallow and eutrophic lakes. An investigator must therefore pay attention to the presence of aquatic mosses. The methods to be used depend on the amount of aquatic mosses, the width of willow zones and both the amount and quality of peat (Fig. 2).

Besides macrophyte investigations in the most important objects of restoration, one must study bottom sediment, zoobenthos and ichtyofauna. In waterfowl wetlands the most important nesting and eating areas of water birds must be marked down on a map, in order to make it possible to pay attention to them, e.g. when the dredging plan is made.

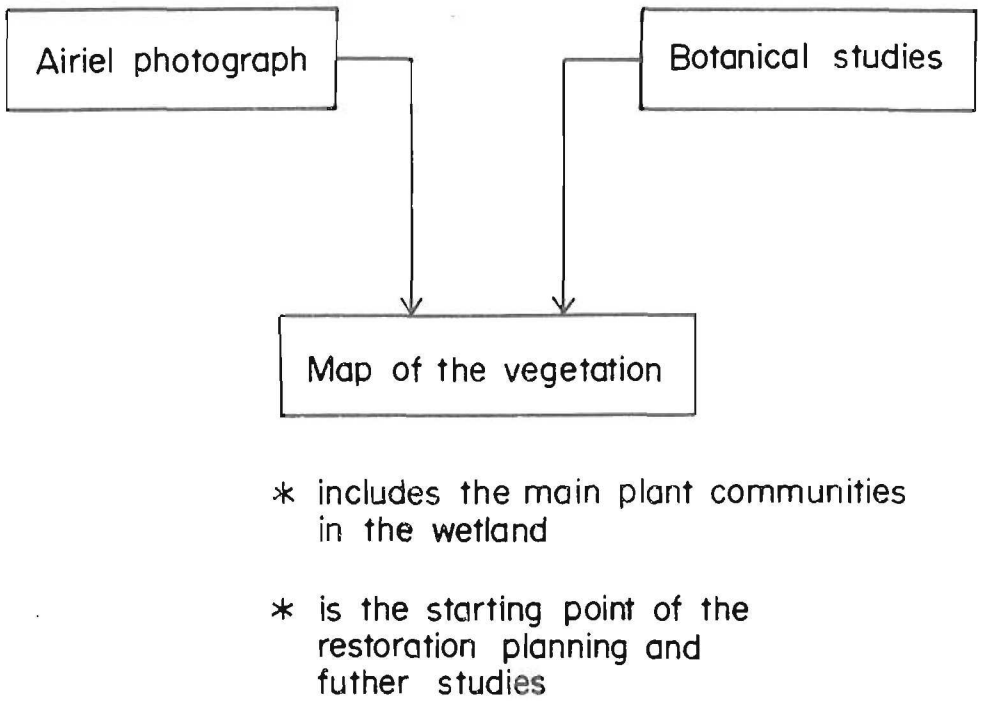

Figure 2. Research of aquatic vegetation in the water area.

4 WATERFOWL WETLANDS

Most of the waterfowl wetlands have been born, because the water level has been lowered about 40-100 years ago and nowadays they have a tendency to be overgrown by tall reedy helophytes or sedges and later on by Salix shrubs. The characteristic feature of these lakes is a rich aquatic moss vegetation especially in sheltered bays. On the basis of the water quality,

the lakes can be classified as mesotrophic or eutrophic.

The waterfowl wetlands restoration is founded on the national wetland conservation program, which was completed in 1981. The program includes 287 protected areas. Some of them are gulfs, some are lakes or bays of lakes.

Water and Environment Administration has made restoration plans for the waterfowl wetlands which are in the worst condition. One of these lakes is Lake Tuomiojärvi in Jäppilä.

5 LAKE TUOMIOJÄRVI AND MACROPHYTE COMMUNITIES

Lake Tuomiojärvi is located in the Finnish Lake District in the northern part of the region of Mikkeli. Lake Tuomiojärvi is included in the program, which tries to protect the most important wastelands for the waterbirds. This area is very remarkable, because it is one of our internationally protected areas for the birds

Lake Tuomiojärvi is a very shallow lake, because the water level has been lowered at the beginning of this century. Eutrophication has produced large and thick macrophyte communities. Today there are too many helophytes for the birds and that is why it is necessary to restore the lake (Hiltunen 1984).

The most common macrophytes in Lake Tuomiojärvi are *Equisetum fluviatile, Schoenoplectus lacustris, Nymphaea* sp., *Nuphar* sp., many species of *Carex* and *Lemna minor*. Besides the fact that there are a lot of macrophytes in Lake Tuomiojärvi, it is also full of mosses. Bryophytes are common, especially in open water and they are usually, but not always, under the water level. The most common bryophytes are *Drepanocladus tenuinervis, Warnstorfia trichophylla, Fontinalis hypnoides* and *F. antipyretica*.

In spite of the great amount of aquatic vegetation, the number of species on the water area is relatively low. The changes in the aquatic vegetation of Lake Tuomiojärvi partly represent the natural succession of the vegetation, which has been accelerated by the lowering of the water table (Hinneri 1965). Other changes can be ascribed to the impact of man in recent times.

6 LAKE RESTORATION TECHNIQUES

The best way of repairing this kind of lake is to raise the water level by at least half a meter. It is, however, impossible to raise the water level in

Lake Tuomiojärvi, because it will cause a lot of damage for forestry and agriculture. That is why helophytes have been cut there in three summers. The modern aquatic weed harvester does an effective job of cutting the tops of plants. After cutting, the plants should be collected and taken away from the lake (Riemer 1984).

In the southern part of the lake it is impossible to cut the vegetation, because there is hardly any water left. That is why a special "walking harvester" has been used there. It is good especially for the restoration of eutrophic lakes, because it can be used in less than half a meter of water. It is easy to transport on roads and move into lakes, and it can dig any kind of bottom, also in winter.

According to the plan, there has been an attempt to repair Lake Tuomiojärvi, so that the protected area would preserve its importance. Water birds need open waters and that is why aquatic vegetation has been taken away in some parts of the lakes.

After all this, studies will be made on how the lake will change and especially what will happen in the restored areas. There are ten other similar lakes in Finland, which need to be repaired for the birds, and hundreds of lakes which ought to be repaired for people.

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METHODS FOR SAMPLING AQUATIC VEGETATION USED BY THE WATER AUTHORITIES IN FINLAND

Carita Nybom
National Board of Waters and the Environment
PB 250, SF-00101 Helsinki, Finland

1 INTRODUCTION

All higher aquatic plants and those of the lower ones which can be seen without magnifying lenses are defined as macrophytes.

By studying the aquatic vegetation we get information about the trophic status of a watercourse and the changes in it. The macrophyte vegetation changes when its environment changes, but more slowly than the microscopic phytoplankton does. In this way the macrophytes reflect the changes that take place during a longer period of time and those which have taken place further back in the past.

Changes in the aquatic vegetation are caused by natural factors, such as the lowering of the water level and the change in the trophic status. Man imposes many changes on the environment of the macrophytes. Eutrophication of the water caused by the waste water load from different sources, agriculture, forests and building in the watercourses belongs to man-made factors. The most important reason for the overgrowth of the watercourses by aquatic weeds has, however, been the lowering of the water table of lakes for drainage purposes at the end of the 19th century.

The sampling methods of aquatic plants have not been standardized in Finland, and even less so in the whole world. The methods described here are standardized only for use in research carried out by the National Board of Waters and the Environment (Vesi- ja ympäristöhallitus 1990).

Studies of the littoral vegetation are carried out by the water authorities mainly when they are making plans for lake restoration, and during the follow-up of the results. Lakes important due to their natural value are more and more often included in the research programme.

The planning and the actual carrying out of the research demands a good knowledge of aquatic botany.

2 MAPPING OF THE AQUATIC VEGETATION

The zonation of the vegetation, the location of stands of different species, their size and composition, and the frequency, distribution and abundance of indi-

vidual species is studied by mapping the vegetation in the watercourse. The extent and the accuracy of the mapping depends on the plans for the future use of the watercourse. When, for instance, a change in the water table is planned, the mapping must include the vegetation beneath the mean high water level. Often it is sufficient to map the vegetation beneath the mean water level. This means that also shore plants have to be taken into consideration.

The mapping is done with the help of aerial photography and field work. Aerial photography is essential, because it is time-saving and increases the reliability of the map. The ideal sequence of work is as follows:

1. Aerial photography
2. Drawing a sketch of the map
3. Field work
4. Finishing the map.

Especially lakes valuable due to bird life require the following measurements:

1. A vegetation map
2. A species list
3. The cover, abundance and frequency of the most important species
4. A description of the zonation of the whole vegetation based on aerial photography and line transects.

2.1 AERIAL PHOTOGRAPHY

The following equipment is required:

- a small aeroplane suitable for aerial photography
- a system camera for 35 mm film with a normal objective lens of 50 mm with UV-filter
- colour slide film of the sensitivity 64-100 ASA
- a general map.

The best time of day for aerial photography is before noon, and the optimal time in the vegetation season is from the middle of July to the beginning of September. The sky should be clear or have a light but homogeneous cloudiness. The photos are taken straight down, either through an opening on the bottom of the plane, or through a window. The flying altitude should be around 500-1000 m depending on the size of the lake. The exposure time should be 1/250-1/500 seconds.

2.2 DRAWING THE SKETCH MAP

The slides are shown on a wall on the presumptive map in the desired scale. The boundaries of the vegetations of different species are drawn, and every species is marked with its own sign or colour.

2.3 THE FIELD WORK

The following equipment is required:

- a sketch of the vegetation map
- a general map
- a compass
- a piece of hardboard underneath the vegetation map
- formulas, possibly partly filled with the names of the most common species for observation of the plants in every sample quadrat (Appendix 1)
- a string for making the transect line with markings at every meter
- wooden poles for marking the start and the end of the transect line and for fastening the string
- a wooden frame, in the size of 0.5 m x 0.5 m or 1 m x 1 m, and a metal frame in a smaller size, for marking the study square
- a water viewing box, ready-made (Fig. 1) or handmade. A piece of plastic tube with a diameter of 20 cm and a length of 60 cm is closed watertight at one end with a piece of plexi glass and to the other end of which a pair of handles is attached
- a sampling rake (Fig. 2).

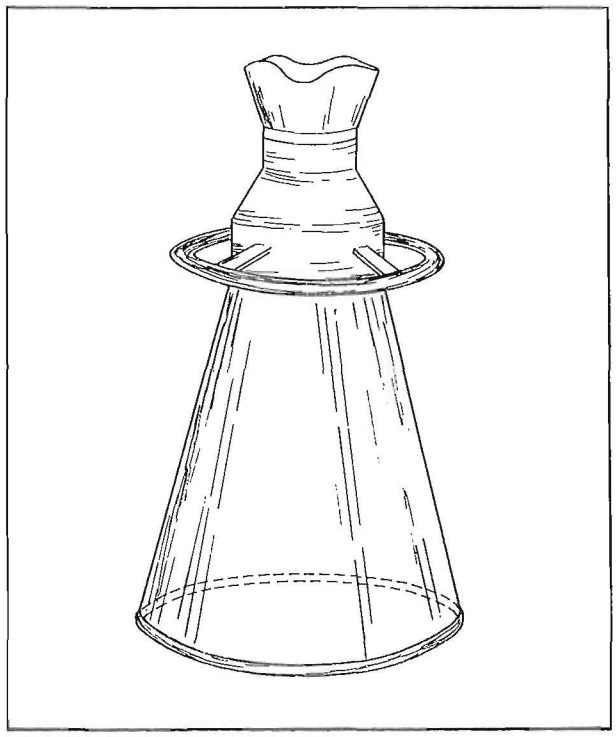

Fig. 1. A water viewing box.

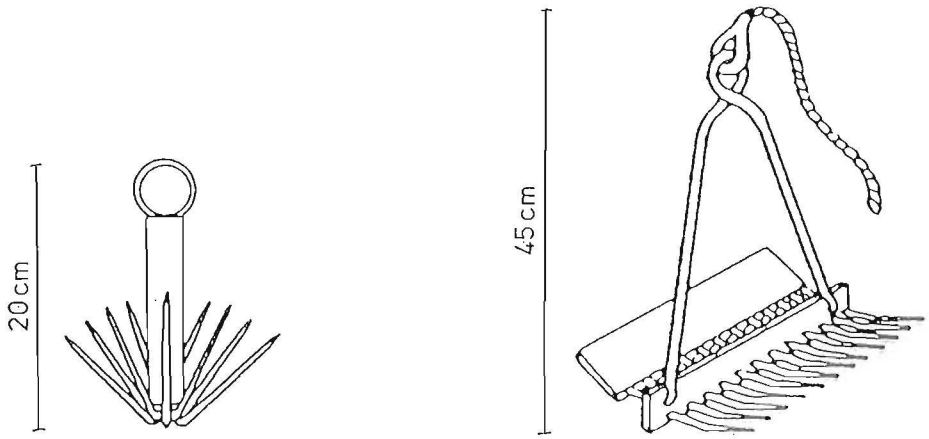

Fig. 2. The "Maristo" sampling rake (left) and the "Luther" sampling rake (right).

Every species should be marked with its own sign in the sketch map. Later, when making the final map some of the rarest species can be omitted, but a concept of their location is necessary. The water authorities use their own signs for the species (see example in Appendix 2), but there are no standardized signs in Finland.

The area to be mapped is divided into parts with the help of the aerial photos. Every part consists of a relatively easily recognizable vegetation type. Inside every part one research line (or belt) transect is selected randomly. The starting point of the line is defined by the help of the compass and two distinctly recognizable points on the opposite shore. The starting point is in the section of the lines drawn from these two points. The direction of the transect should be at right angles to the shore. The level of the starting point is at the mean water level and the end point at the outer edge of the vegetation until no plants are observed. The exact position of the line is marked on the map in terms of the coordinates of the starting point. The direction of the line is marked in terms of its compass direction. If a monitoring programme of several years is planned, the position of the starting point should be tied to an easily recognizable and stable mark in the terrain.

At every meter, or at every second meter, along the line a sample quadrat is studied. The size of the quadrat or square is 1 m^2 in the shore vegetation and 0.25 m^2 in water vegetation. In a homogeneous vegetation the samples can be even more sparse.

In every quadrat the water depth, plant species and the cover (of every one) is observed. The following classes of cover percentages are used: <1, 2, 5, 15, 25, 50, 100.

The coverage corresponds to abundance as follows:

< 1 %	very scarce (pcc)
1 - 2 %	scarce (pc)
3 - 5 %	relatively scarce (st pc)
6 - 15 %	dispersed (sp)
16 - 25 %	relatively abundant (st cp)
26 - 50 %	abundant (cp)
51 - 100 %	very abundant (cpp).

The frequency of a species is acquired from the observation of in how many sample quadrats it occurs. The percent frequency corresponds to the frequency classes as follows:

1 - 2 %	very rare (rr)
3 - 8 %	rare (r)
9 - 18 %	relatively rare (st r)
19 - 32 %	spatial (p)
33 - 51 %	relatively frequent (st fq)
52 - 73 %	frequent (fq)
74 - 100 %	very frequent (fqq).

3 MEASUREMENT OF GROWTH (STAND) DENSITY

The number of samples, i.e. quadrats of squares, is 100/stand. In a very dense and uniform vegetation less than 100 may be sampled, but the smallest number of quadrats is 50.

The growth or stand density is measured especially when monitoring the control of aquatic weeds. Added to the measurement of the biomass it gives a good picture of the effectiveness of the control method. The definition of the growth density is part of the method for the measurement of biomass described in Chapter 4. This method is suitable for nearly pure macrophyte stands (with less than 5 % of other species).

The equipment is the same as for the field work in mapping, with the exception of a sketch map.

The research area is chosen in a homogeneous vegetation, and the transect line is selected randomly inside of it.

The sample squares are marked with the frame and placed one after one another along the line. All the plants inside the frame are counted. Only those which have their above water parts inside the frame are counted. It is easiest to handle the frame in

parts in a helophyte stand, and as a whole in a stand of nymphaeids. For studying submerged plants a frame with a long handle and a viewing box is used.

4 MEASUREMENT OF THE ABOVE GROUND BIOMASS AND THE SIZE OF INDIVIDUAL PLANTS

The aim of the measurement of the biomass is the same as of the measurement of the growth (stand) density. The above ground biomass is acquired by multiplying the mean stand density - for nymphaeids the number of leaves - with the average weight of one shoot.

For the method described here it is presumed that the density of the stand is measured as described in Chapter 3. This method is best applicable for helophytes.

The equipment is the same as for the field work in mapping, with the exception of a sketch map. Added to these are:

- a sickle with a long handle
- plastic and paper bags of different sizes
- newspapers
- movable scales.

From the vegetation stand under study 50 - 100 shoots are randomly selected and cut as close to the bottom as possible. Each is rinsed carefully and any loose parts are collected. The samples are stored and transported in plastic and paper bags.

When sampling is done in submerged or clumped communities, all the plants in a quadrat must be collected. The submerged plants are collected by cutting them inside a metal frame. The stand can be reached by wading or diving. Alternatively, bottom samples or dredge can be used.

The fresh weight is measured in the field. If it is done later, the samples can be stored for 24 hours in a cool place (+2° - +4°C) in plastic bags.

Before the measurement of the fresh weight, the plants are spread out on a newspaper in the open in a shaded place or indoors in room temperature. The plants are ready to be weighed when all surface water has evaporated. The length of all - or, for instance, every other shoot is measured. Of the nymphaeids the combined length of the balde and the stal is measured. The size of the blade is measured according to Fig. 3.

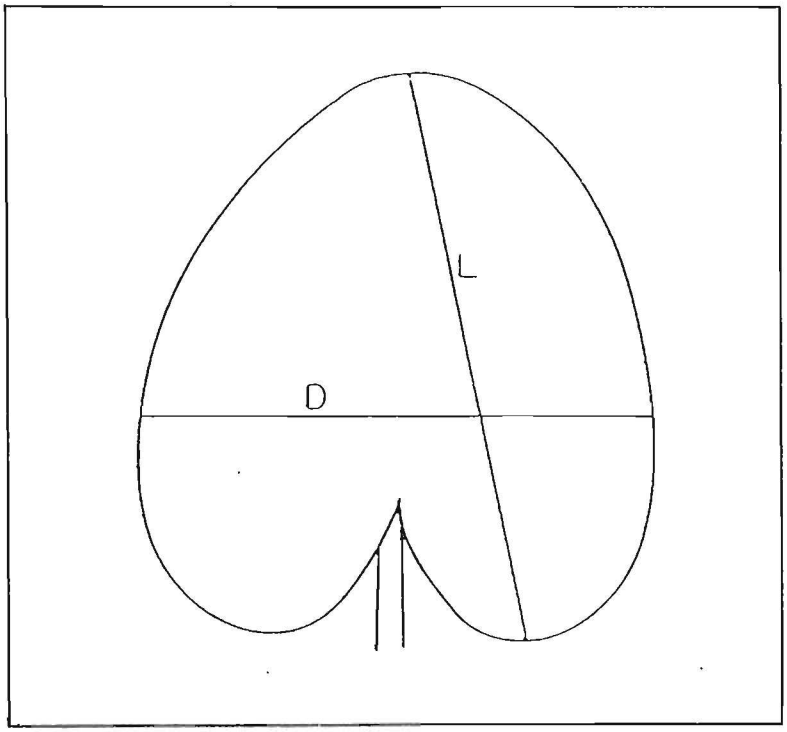

Fig. 3. Measurement of the area of a nymphaeid leaf. D = maximum breadth, L = maximum length, k = 0,95 (Hiltunen 1981).

The shoots are weighed in bundles of 20 and the average weight of one shoot is calculated. One bundle is taken as a subsample for the measurement of the dry weight and stored in a paper bag.

The subsample is dried at 105°C for 24 hours. It is cooled during one hour in an exicator. The dry weight of the whole sample is calculated from the dry weight of the subsample.

When monitoring a stand during several years, sampling from exactly the same place must be avoided. This means that the transect line has to be extended to a transect belt covering the estimated need of the sample area.

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Lake _____ Date _____

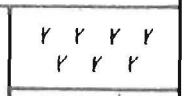
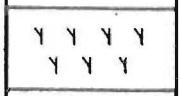
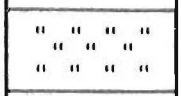
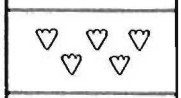
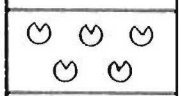
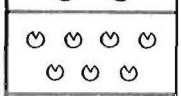
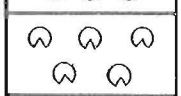
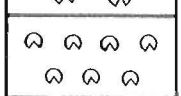
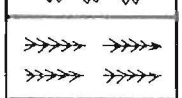
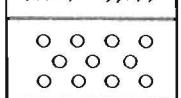
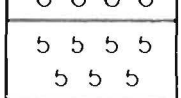
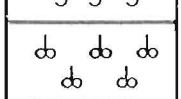
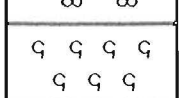
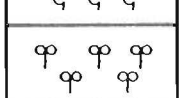
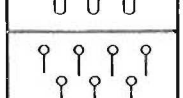
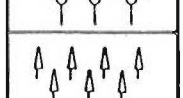
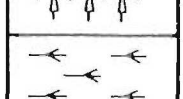
Station _____

Line _____ Square _____ Distance from the beginning of the line _____

Isoetes lacustris	37			
Isoetes echinospora	37			
Equisetum fluviatile	38			
Nymphaea candida	57			
Nymphaea tetragona	57			
Nuphar lutea	57			
Nuphar pumila	58			
Ceratophyllum demersum	58			
Caltha palustris	61			
Ranunculus repens	68			
Ranunculus reptans	76			
Ranunculus peltatus	77			
Stellaria palustris	95			
Polygonum amphibium	124			
Elatine hydropiper	135			
Elatine triandra	135			
Viola palustris	139			
Rorippa palustris	150			
Cardamine pratensis	151			
Subularia aquatica	164			
Lysimachia vulgaris	194			
Lysimachia thyrsiflora	194			
Potentilla palustris	223			
Lythrum salicaria	258			
Epilobium palustre	263			
Myriophyllum alterniflorum	266			
Cicuta virosa	284			
Galium palustre	293			
Menyanthes trifoliata	299			
Myosotis scorpioides	314			
Mentha arvensis	327			
Callitriche palustris	330			
Veronica scutellata	340			
Pedicularis palustris	348			
Utricularia intermedia	355			
Utricularia vulgaris	355			
Hippuris vulgaris	356			
Lobelia dortmanna	361			
Bidens tripartita	373			
Iris pseudacorus	448			
Calla palustris	458			
Lemna minor	459			
Sagittaria sagittifolia	460			
Sagittaria natans	460			
Alisma plantago-aquatica	461			
Hydrocharis morsus-ranae	462			

Stratiotes aloides	462
Potamogeton natans	465
Potamogeton lucens	466
Potamogeton perfoliatus	467
Potamogeton friesii	467
Potamogeton berchtoldii	468
Potamogeton obtusifolius	468
Potamogeton compressus	468
Sparganium gramineum	473
Sparganium emersum	473
Sparganium angustifolium	474
Sparganium minimum	474
Typha latifolia	475
Juncus filiformis	477
Juncus alpinoarticulatus subsp. nodulosus	480
Scirpus sylvaticus	485
Schoenoplectus lacustris	485
Eriophorum angustifolium	487
Eriophorum vaginatum	488
Eleocharis acicularis	489
Eleocharis palustris	490
Carex diandra	499
Carex chordorrhiza	501
Carex canescens	504
Carex lasiocarpa	507
Carex rostrata	509
Carex vesicaria	509
Carex pallescens	515
Carex limosa	519
Carex magellanica	519
Carex aquatilis	522
Carex nigra, nigra	524
Carex nigra, juncella	
Carex acuta	524
Festuca rubra	531
Glyceria lithuanica	542
Glyceria maxima	542
Deschampsia flexuosa	551
Calamagrostis purpurea	556
Alopecurus geniculatus	559
Alopecurus aequalis	559
Phalaris arundinacea	559
Phragmites australis	561

SYMBOLS FOR MACROPHYTES

Finnish name	Scientific name	
Tummalahnaruoho	Isoetes lacustris	
Vaalealahnaruoho	I. echinospora	
Järvikorte	Equisetum fluviatile	
Isolumme °, –P	Nymphaea alba	
Pohjanlumme	N. candida	
Suomenlumme ooo P	N. tetragona	
Ulpukka °P	Nuphar lutea	
Konnanulpukka °	N. pumila	
Karvalehti °°E, –P	Ceratophyllum demersum	
Rentukka	Caltha palustris	
Pyörösätkin °°	Ranunculus circinatus	
Järvisätkin	R. peltatus	
Purosätkin °°	R. trichophyllus	
Merisätkin °	R. baudotii	
Rantaleinikki	R. reptans	
Jokileinikki ooo P	R. lingua	
Paunikko °E,ooo P	Crassula aquatica	
Kurjenjalka	Potentilla palustris	
Rantakukka	Lythrum salicaria	
Kiehkuraärviä °°	Myriophyllum verticillatum	

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